

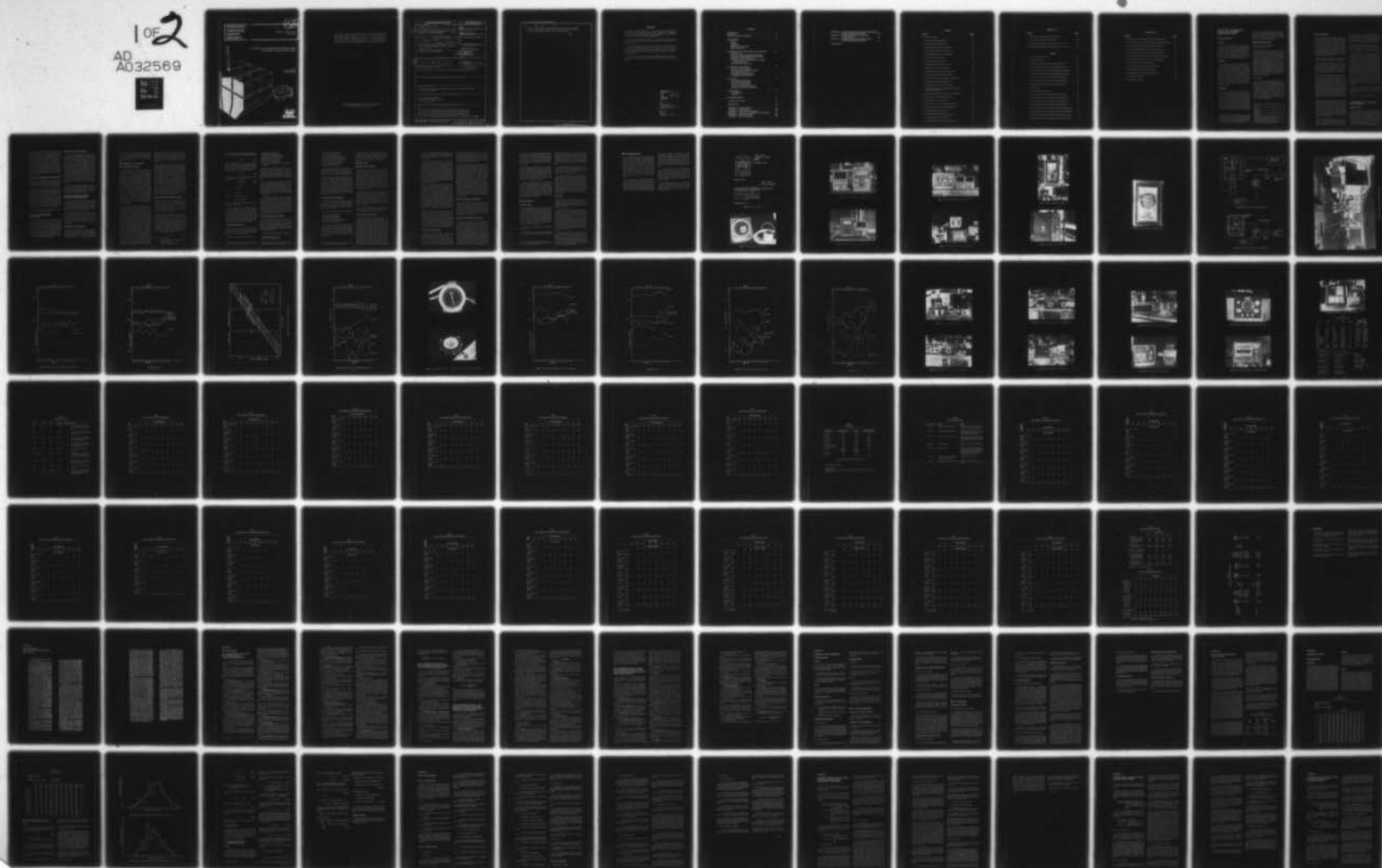
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EVALUATION OF LOAD-INDICATING DEVICES (LIDS) FOR MOBILE CONSTRU--ETC(U)
OCT 76 M J ROSENFELD, B H WENDLER
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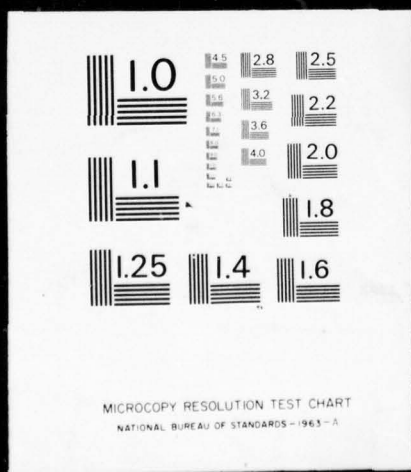
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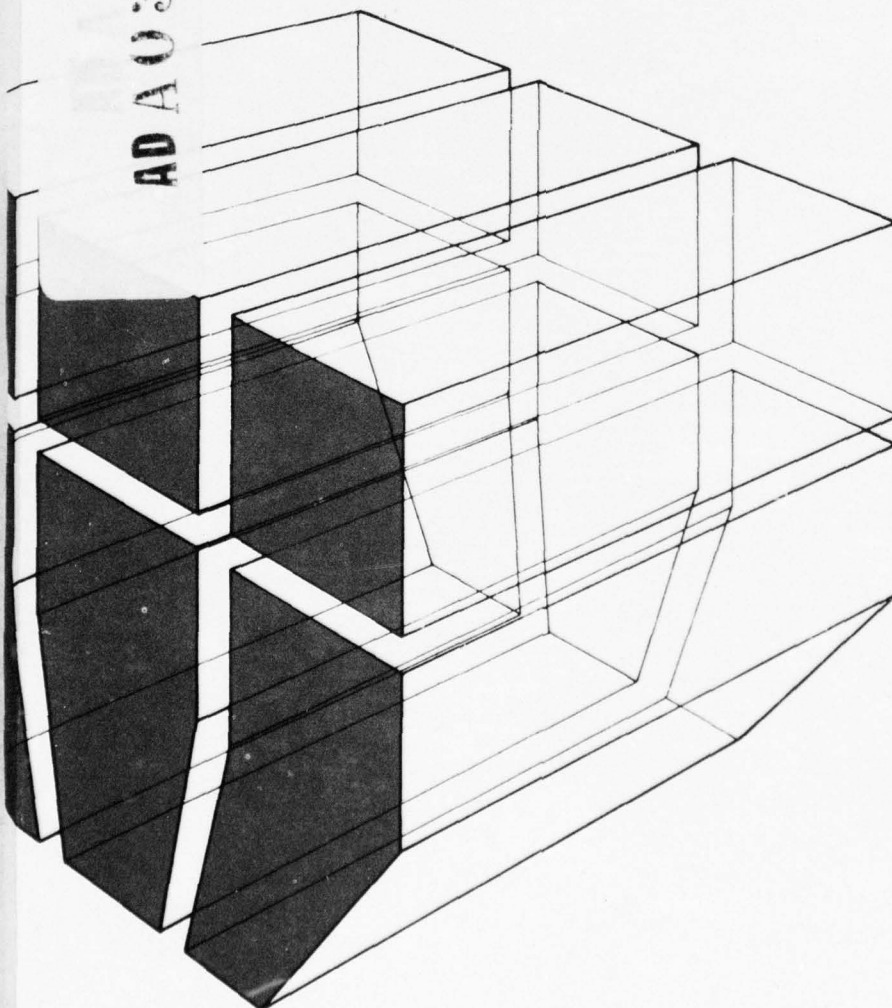


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October 1976

EVALUATION OF LOAD-INDICATING DEVICES (LIDS)
FOR MOBILE CONSTRUCTION CRANES

by
Myer J. Rosenfield
Bruce H. Wendler



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between -50° and $+150^{\circ}$ F (-45.6 and 65.6° C). Results of the tests and an analysis of the data are presented. Functioning ability and accuracy of load-, angle- or radius-, and load-moment indicating systems were found to be satisfactory.

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FOREWORD

This research was performed by the U.S. Army Construction Engineering Research Laboratory (CERL) for the Office of the Chief of Engineers (OCE), Design and Construction Safety Office, under Intra-Army Orders DAEN-SO 73-7 and DAEN-SO 74-1. Mr. W. F. Noser was the OCE Technical Monitor.

The study was conducted by CERL's Structural Mechanics Branch (MSS), Materials and Science Division (MS). Mr. Myer J. Rosenfield was Principal Investigator for the work.

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COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Deputy Director. Dr. W. E. Fisher is Chief of MSS and Dr. G. R. Williamson is Chief of MS.

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EVALUATION OF LOAD-INDICATING DEVICES (LIDS) FOR MOBILE CONSTRUCTION CRANES

1 INTRODUCTION

Purpose

The purpose of this study was to determine the precision and accuracy of available types and makes of load-indicating device systems (LIDS) for use with mobile construction cranes (the criteria to be used in evaluating the LIDS were the Society of Automotive Engineers [SAE] standards¹); to recommend a candidate performance specification; and to determine unsatisfactory defects in current products.

Approach

Known LIDS manufacturers in the United States were surveyed in September 1972. LIDS were purchased from those manufacturers who marketed them independently for installation on existing cranes, and could meet delivery schedules compatible with the test program. Six load indicators, five boom angle indicators, and five load moment computers were tested in the laboratory for compliance with SAE standards. In cooperation with Corps of Engineers Districts, limited field tests were conducted on five load indicators, three angle indicators, and two load moment computers which were already in service.

Background

The Corps of Engineers has long been concerned with safe operation of mobile construction and maintenance cranes and use of devices which indicate the approach or existence of unsafe operating conditions. The Portland District has conducted investigations of construction crane safety and use of LIDS since 1955; other Districts have been conducting similar programs for several years. This study was undertaken to evaluate the accuracy and reliability of a representative sample of commercially available LIDS. Although the Corps does not require

use of LIDS, it does require that portal, hammer-head, and tower cranes be equipped with load-limiting devices which effectively prevent overloading beyond the manufacturer's ratings at any load, boom radius, and counterweight position.²

Regulations and Standards

Occupational Safety and Health Administration Regulations

After establishment of the Occupational Safety and Health Administration (OSHA) in 1970, regulations on the use of LIDS in the longshoring industry were proposed for public review and comment³ and were subsequently adopted in May 1972. Appendix A contains a copy of the published regulations.⁴ The regulations, which apply only to cranes for use on shipboard, for servicing ships from shore, and for loading and unloading cargo, require use of boom-angle- and load-indicating devices. The regulations describe the function and required accuracy of the devices, but do not establish the systems' principle of operation. Similar regulations were proposed for the construction industry,⁵ but the effective date has been postponed indefinitely.

SAE Standards

SAE has published recommended practices concerning load- and boom-angle-indicating devices. SAE J375a⁶ covers radius-of-load and boom-angle-measuring systems, and SAE J376a⁷ covers load-indicating systems. A third standard, SAE J159,⁸ deals with load-moment-indicating devices. These standards (Appendix B) define the performance, installation, and maintenance requirements, and evaluation tests applicable to the indicating devices. They do not regulate the use of these devices; regulation is the function of OSHA.

¹SAE Recommended Practice for Radius-of-Load and Boom Angle Measuring System, SAE J375a (Society of Automotive Engineers [SAE], 1972); SAE Recommended Practice for Load Indicating Systems in Lifting Crane Service, SAE J376a (SAE, 1974); SAE Recommended Practice for Load Moment Warning System, SAE J159, proposed revision (SAE, 1976).

²General Safety Requirements, EM 385-1-1 (Department of the Army, 1967).

³Federal Register, Vol 36, No. 104 (May 28, 1971), pp 9772-9773.

⁴Federal Register, Vol 37, No. 203 (October 19, 1972), pp 22541-22542.

⁵Federal Register, Vol 36, No. 188 (September 28, 1971), pp 19087-19088.

⁶SAE Recommended Practice for Radius-of-Load and Boom Angle Measuring System, SAE J375a (SAE, 1972).

⁷SAE Recommended Practice for Load Indicating Systems in Lifting Crane Service, SAE J376a (SAE, 1974).

⁸SAE Recommended Practice for Load Moment Warning System, SAE J159, proposed revision (SAE, 1976).

Types of Equipment

LIDS is a generic term which includes more than simple load indicators. Some systems indicate angle of the boom or radius to the load. Others indicate the percentage of maximum allowable load moment for the conditions at the time of the lift. Combinations of these indications are available, as are means of presetting the maximum working load and the range of operation of the boom. Visible and/or audible warnings indicate that these limits have been approached or reached. None of the systems affect the actual operation of the crane.

LIDS manufacturers use three basic principles of operation—mechanical, hydraulic, and electrical.

Mechanical operation is confined to boom angle sensors. Because of the arrangement required to operate this type of equipment, they could not be placed into the environmental chamber used in this study and caused to function. Consequently, mechanical boom angle sensors were not tested.

Hydraulic load indicators consist of a load cell to sense the load, a hose or tube to transmit pressure from the cell, and a bourdon tube indicator to display the results. Hydraulic load cells are of two types—piston and diaphragm. In the first type, a piston moving within a cylinder develops pressure within the confined hydraulic fluid. In the second type, the piston is suspended on a diaphragm. Applying the load moves the piston into a chamber, thus developing pressure within the confined hydraulic fluid; the piston does not fit snugly within the chamber's wall. Figure 1 illustrates piston and diaphragm load cells. Figure 2 shows a typical hydraulic load cell and indicator.

Hydraulic boom angle indicators consist of a small container of hydraulic fluid suspended on the boom 50 ft (15.24 m) from the hinge, a bourdon tube indicator in the crane's cab, and a hose connecting the two. The bourdon tube indicator shows changes in container elevation caused by changes in boom angle. Because the testing room had neither the floor space nor ceiling height required for suspension and elevation of the container, this type of indicator was not tested in the laboratory.

Electric or electronic load indicators consist of a load cell to sense the load and convert it to an electric signal, an amplifier to amplify the signal, and a means of displaying the results to the crane operator.

Electric load cells are of two types—resistance and inductive. Resistance cells usually consist of a strain gage on the surface of a small metal cylinder. Inductive cells consist of a linear variable differential transformer (LVDT) within a suitable container.

Electric boom angle indicators consist of a pendulum-potentiometer located on the boom near its hinge, an amplifier to amplify the signal, and a means of displaying the result to the crane operator.

The basic types of electric indicators can be made more elaborate in several ways. Load indicators can be equipped with dials for setting a predetermined maximum load (Figure 3). When lifting this or a larger load is attempted, alarms—visible, audible, or both—warn the operator that the crane's limit has been reached or exceeded. Boom angle indicators can be equipped with dials for setting predetermined high and low boom angles for the particular conditions of operation (Figure 4). When either of these angles is reached or exceeded, alarms—visible, audible, or both—warn the operator that the boom has been raised or lowered too far. The output signals from the load cell and the boom angle sensor can be combined in a miniature computer; the display shows the operator the percentage of maximum overturning moment (Figures 5 and 6) for the crane for the particular combination of load and boom angle being used.

Dials are also available which set the number of parts-of-line to which the crane can be rigged and the various combinations of booms and jibs which can be installed.

Tables 1 and 2 summarize the LIDS tested in this study.

2 LABORATORY TEST PROCEDURES AND EQUIPMENT

Laboratory Tests

Tests performed on LIDS in the laboratory were designed to examine the devices' performance under controlled environmental conditions. Load cells and boom angle sensors were operated within an environmental chamber at temperatures from -50° to $+150^{\circ}\text{F}$ (-45.6° to 65.0°C), and humidities of 20 to 90 percent at temperatures above 40°F (4.4°C). The components were calibrated against standard indicators for both increasing and decreasing values of

the load or boom angle variable to determine the following properties of the indicating devices: linearity of response, presence of hysteresis, variation of response with temperature, and capability of surviving extreme temperatures. After the sensors were calibrated, the complete LIDS were operated to verify the accuracy of the indicated load and boom angles and load moments, and the activation of audible and visible alarm signals. After all operational tests were completed, survival of the load cells was checked by loading the cells with a suddenly applied (shock) force equal to three times their rated capacity. Appendix C includes the complete laboratory procedure.

Equipment for Applying and Measuring Loads

Load cells were calibrated and tested using electrohydraulic equipment which permitted application of predetermined static or dynamic loads. Appendix D contains a complete description of the equipment.

Hydraulic load cells were calibrated using a Type 1305-B10 Ashcroft portable deadweight tester manufactured by Manning, Maxwell & Moore, Inc. The tester was connected directly to the hose from the load cell; the pressure in the system caused the applied weights to rise, indicating that the system was in equilibrium. Instead of applying the load in tenths of the maximum cell rating, as was done for electric cells, the increments were determined by the deadweight tester; the loads which balanced these increments were read from the testing machine.

All load cells were tested in compression; Figure 7 shows a typical load cell installation.

Equipment for Simulating Boom Angle Changes

Raising and lowering of crane booms were simulated using a machine shop rotary table (Palmgren No. 1062) with a 10-in. (25.4 cm) diameter face. This table can be rotated 360 degrees; angles can be read to one-twentieth of a degree. An aluminum plate was fastened to the face of the table, drilled, and tapped to accommodate the various boom angle sensors tested in the program. The rotary table was controlled by a handwheel with dial and indicator outside the environmental chamber (Figure 8). Figure 9 shows a typical angle sensor installation.

Environmental Control Equipment

The environmental chamber was designed for use with the 50- and 1,000-kip (222 411 and 4 448 222 N) load frames described in Appendix D. The chamber sits between the columns of the load frame and surrounds the test specimen. Refrigerated and/or heated air is supplied to the chamber through a closed recirculating system; temperatures can be maintained between -100° and $+300^{\circ}\text{F}$ (-73.3° and 148.9°C). The system can also generate and maintain any desired relative humidity between 0 and 100 percent at any temperature above 32°F (0°C). The environmental chamber is controlled by a closed-loop system which maintains the desired temperature and humidity. Temperatures within the chamber were monitored using an iron-constantan thermocouple to check the condition of the refrigeration system.

Only the load cells and boom angle sensors were placed in the chamber. All display and electronic modules were outside on the test bench so that maximum angle and load settings could be changed as needed during calibration and testing.

Equipment for Measuring the Output of Load Cells and Angle Sensors

The voltage signals from boom angle indicators and electric load cells were taken from the terminals of the indicating meters and read on a Systron-Donner model 1936 integrating digital voltmeter after passing through the conditioning and amplifying sections of the equipment being tested.

Lead cables from both systems were brought into a common switch box from which the selected signal could be displayed on the digital voltmeter. Figure 10 shows a connection diagram of the system components for load indicators and Figure 11 for the boom angle indicators. Figure 12 shows the complete test arrangement.

Calibration of Test Equipment

The load cells used in the U.S. Army Construction Engineering Research Laboratory (CERL) Materials Testing System and all other test instruments used at CERL are calibrated semiannually by the Mobile Calibration Facility of the Lexington Blue Grass

Army Depot. Their equipment is calibrated every 90 days on equipment directly traceable to the National Bureau of Standards. Since the CERL load cells are used at room temperature at all times, no further calibration was done.

3 LABORATORY TEST RESULTS

Load Cell Calibration Results

A linear regression analysis was performed on all load cell calibration data. Appendix E includes a discussion of the design and validity of the analysis, a listing of the computer program REGRAN (REGRESSION ANALYSIS) developed to compute the coefficient of variation for each calibration run, and typical data taken during calibration runs. All data taken are on file at CERL. From the analysis, the standard deviation was computed for each temperature at which the calibration run was performed. The standard deviation was then divided by the data mean value to obtain the coefficient of variation (COV). A plot of the COV values versus temperature indicates the precision of a particular indicating system in a varying temperature environment (Figure 13). The values of the COVs of the load indicators varied less than 0.6 percent over the entire temperature range for all load-sensing devices tested, showing that each device exhibited essentially constant accuracy.

A linear regression analysis was also used to compute hysteresis factors. In each calibration run, data were taken while the load was increasing and decreasing. In the regression analysis, linear equations were fitted to the increasing and decreasing load data (Figure 14). The area between the "raise and lower" linear equations in the data field was designated the hysteresis area. Dividing the hysteresis area by the arithmetic mean value of the variables from which it was determined gave a dimensionless parameter; dimensionless parameters are used to compare the behavior of a model to a prototype or another model. Consequently, the derived parameter allowed a comparison between systems and an indication of the effects of temperature on hysteresis. Figure 15 is a graph of the hysteresis coefficients of the tested LID systems versus temperature. The hysteresis factor of the load indicators varied less than 1.5 percent in value over the entire temperature range for all load-sensing devices tested, showing that each device exhibited essentially constant hysteresis. Calibration of hydraulic load cells was performed using a deadweight tester. If weights were

removed from the tester while the cell was under a load, the tester's piston was forced out of its cylinder. For this reason, removing the weights and bringing the load down to the corresponding value was impossible; hysteresis could therefore not be determined.

Low temperature extremes had little impact on resistance-type electronic load cells. Figure 13 shows that the Markload Systems III and V (manufactured by Mark Products), SEQ, Dillon, Litton, and Forney systems remained unchanged through the temperature range. The two induction system (Eaton models PA 173 and PA 166) COVs decreased 30 and 75 percent respectively from -30° to -50°F (-34.4° to -45.6°C). Hydraulic system COVs drifted upward as the temperature decreased below 10°F (-12.2°C). The COV of the Pennant system increased 150 percent from 10° to -50°F (-12.2° to -45.6°C); however, at -50°F (-45.6°C) the COV level was still only .65 percent. The Martin Decker hydraulic system experienced a 33 percent increase in COV from 10° to -50°F (-12.2° to -45.6°C). At -50°F (-45.6°C) the Martin Decker System failed due to rupture of the diaphragm (Figure 16).

Boom Angle Sensor Calibration Results

A linear regression analysis (Appendix E) was also performed on the boom angle calibration data. Figure 17 shows the accuracy of various manufacturers' equipment in terms of the COV versus temperature. In general, the COV increased at the lower temperature ranges. Most of the systems maintained a COV below 2.0 percent.

Hysteresis was computed for each calibration run as outlined previously. In general, hysteresis of the systems increased below -10°F (-23.3°C). An indication of the hysteresis factor allowed by the SAE standards was established using the following procedure. Specification SAE-J375a allows a bandwidth of 4 degrees (1 degree under and 3 degrees over) for angles under 65 degrees. The hysteresis factor can be computed by extrapolating this bandwidth to 90 degrees. The equation used in computing the hysteresis in the boom angle data was

$$y = a + \beta x \quad [\text{Eq 1}]$$

where y = output voltage

a = offset voltage when the angle equals zero

x = actual boom angle

β = slope of the linear equation.

Given a linear equation which intersects the origin, a parallel equation which allows a 4-degree bandwidth is

$$y = 4^\circ \beta + \beta x \quad [\text{Eq 2}]$$

The area between the two lines between 0 and 90 degrees equals 360β deg-volts. The hysteresis factor (Hf) was computed by dividing this value by the voltage and angle mean. The angle mean (\bar{x}) equals 45 degrees and the voltage mean (\bar{y}) is given by

$$\bar{y} = a + \beta \bar{x} \quad [\text{Eq 3}]$$

The voltage mean is taken from the equation which bisects Eq 1 and $y = \beta x$, which is:

$$\bar{y} = 2^\circ \beta + \beta \bar{x} \quad [\text{Eq 4}]$$

$$\bar{y} = \beta(2^\circ + \bar{x})$$

Since: $\bar{x} = 45^\circ$

$$\bar{y} = \beta(47^\circ)$$

Therefore: $\text{Hf} = 360\beta / 45^\circ / 47\beta$

$$\text{Hf} = 14.035 \text{ percent.}$$

Most boom angle sensors had hysteresis factors below 1.0 percent (Figure 18).

No functional failures occurred in the units over the entire temperature range. Minor failures occurred in some of the units at the low temperature extreme. The outer insulation casing of the cable leading into the boom angle sensor shattered or cracked. Eaton and Litton boom angle sensors experienced breaks in the circuit due to poor contacts in the potentiometer. Vibrations would eventually cause these contacts to close the circuit.

Load Indicator Test Results

SAE-J376a states "The accuracy of the Load Indicating System shall be such that the indicated load is within 97 percent to 110 percent of the actual load."⁹ Thus, a 3 percent overload is allowed.

The systems with load indicators tested were:

⁹SAE Recommended Practice for Load Indicating Systems in Lifting Crane Service, SAE J376a (SAE, 1974).

Dillon model LI-1 (Figure 19)
Eaton model PA-181 (Figure 3)
Mark Products System III (Figure 20)
Mark Products System V (Figure 21)
Pennant model 3L-5 (Figure 2)
Revere model R-899 (Figure 22)
SEQ Crane Overload Warning System (COWS) (Figure 23).

Appendix E presents typical data from tests performed in accordance with the procedure outlined in Appendix C. All the systems underwent alarm, prewarning alarm, and load indication tests, except the Mark Products System V, which has no alarms, and Eaton model PA-181, which has no prewarning system.

Tables 3 through 9 present the percent over-indication or under-indication displayed by the load indicators. A 10 percent over-indication and a 3 percent under-indication are the recommended maximum limits. Only the Pennant system had values outside this range; in that case, the problem seemed to be in the calibration, since the error in indication was consistent.

Load cells were subjected to a shock test (Appendix C) designed to duplicate the impulsive loading a cell would experience if the weight being lifted slipped and suddenly stopped. Load cells were impacted to a load level three times their maximum load capacity. Of the 10 load-indicating devices and load moment computers tested, only the Forney cell failed; when it was checked after the test, there was no indication of response to the load. Table 10 summarizes the performance of the cells.

Boom Angle Indicator Test Results

SAE Recommended Practice J-375a states that "For boom angles 65 deg or more, the indicated angle shall be from $\frac{1}{2}$ deg greater than the actual angle to $1\frac{1}{2}$ deg less than the actual angle. For boom angles less than 65 deg, the indicated angle shall be from 1 deg greater than the actual angle to 3 deg less than the actual angle."¹⁰

The systems with angle indicators tested were:

Castle Model 154 (Figure 24)
Eaton Model PA-166 (Figure 4)

¹⁰SAE Recommended Practice for Radius-of-Load and Boom Angle Measuring System, SAE J375a (SAE, 1972).

Eaton Model PA-173 (Figure 5)
Litton Model 5084 (Figure 6)
Martin-Decker Model ECA (Figure 25)
Mark Indicator Model XV (Figure 26)
Mark Products System III (Figure 20)
Mark Products System V (Figure 21)
Revere Model R-899 (Figure 22)
SEQ Model COWS (Figure 23).

Appendix E presents typical data from tests conducted according to the procedure outlined in Appendix C. Table 11 describes problems which occurred during testing of the boom angle indicators.

Tables 12 through 21 present the variation from actual values of boom angle or radius-to-load indicated by the systems tested. These variations are compared to the allowable limits specified in the SAE requirements. Indication of radius-to-load can vary from 3 percent under to 10 percent over the actual radius. Reading the angle indication meters was limited to an accuracy of ± 1 degree, since the meters were graduated in 2-degree increments. This made the $\frac{1}{2}$ -degree requirement of SAE J-375a difficult to meet.

Load Moment Warning Systems

SAE Recommended Practice J-159 recommends that "accuracy of the Load Moment Warning System shall be such that the 100 percent alarm described in 4.1 shall actuate within 90 to 105 percent of the actual rated load."¹¹

The systems with moment indicators tested were:

Eaton Model PA-173 (Figure 5)
Foney System 20 (Figure 27)
Litton Model 5084 (Figure 6)
Mark Products System III (Figure 20)
SEQ Model COWS (Figure 23).

Tests were made to determine the difference between the indicated alarm load or capacity and the actual overload or overturning capacity. Tables 22 through 26 give results of the tests. The deviations are expressed in terms of percent over and under. A -10 percent to +5 percent bandwidth is recommended by SAE.

Hysteresis can be a significant factor due to the smaller voltage changes at the lower angles. Moment computers operate on the cosine of the boom angle; for small angles, a change of a few degrees results in only a minor change in the cosine of the angle.

4 FIELD TESTS

Description of Field Testing

Field tests were conducted on cranes operated by several Corps of Engineers Districts. Field test procedures were based on the SAE testing requirements (Appendix B). However, the procedures developed for this program (Appendix F) were more comprehensive than the ones required by SAE because of Corps use of cranes on barges or derrick boats as well as on land; use on such locations has different safety requirements. SAE requirements specify the use of only one test weight, while this program used four weights, to test the systems at four points on the crane's load-rating curve.

Preparing the exact weights corresponding to the specified boom angles was not always possible in the field. However, the weights that were prepared were known to the specified accuracy, and so could be used for the testing. It was only necessary to determine the boom angle corresponding to the particular weight; this was done by applying the crane manufacturer's loading data.

Two load moment computers, five load indicators, and three boom angle indicators were tested. Table 2 lists the specific makes and model numbers.

Accuracy of Warning Signals

All systems except the Martin-Decker were equipped with warning signals. Both computers gave warnings at 100 percent of allowable capacity, but only the Markload System III also gave preliminary warnings at 85 percent of allowable capacity. The four load indicators equipped with warning signals gave alarms at 100 percent of the load setting. The Dillon system has a preliminary warning signal at 90 percent of load, and the Revere system has a preliminary warning signal at 85 percent of load; both 90 and 85 percent are nominal values. The three boom angle indicators are equipped with switches which permit the crane operator to preset the high and low angle limits. The signals are activated when the boom angle reaches or exceeds the high angle setting, or reaches or goes below the low angle setting.

¹¹SAE Recommended Practice for Load Moment Warning System, SAE J159, proposed revision (SAE, 1976).

SAE has published recommended practices for the operation of load moment systems, load indicators, and boom angle indicators. They are briefly summarized below.

SAE J-159, *Recommended Practice for Load Moment Warning System*, requires a preliminary warning signal at not over 90 percent of the crane's rated capacity and a second warning signal at 100 percent of the rated capacity, as defined by the crane manufacturer's load rating chart. The 100 percent alarm is required to be accurate within 90 to 105 percent of the rated load capacity; this would permit a 5 percent overload of the crane before warning signal activation. Assuming that the loading chart is based on 75 percent of the actual tipping load, the maximum capacity could conceivably be 78.75 percent of the actual tipping load.

SAE J-375a, *Recommended Practice for Radius-of-Load and Boom Angle Measuring Systems*, has requirements which depend on the variable being measured. Accuracy of radius measurement is required to be within 97 percent to 110 percent of the actual radius, which would establish limits of 3 percent overload and 10 percent underload conditions. Requirements are somewhat different for systems which indicate the boom angle. For boom angles under 65 degrees, the indicated angle is required to be from 3 degrees less than to 1 degree greater than the actual angle. For boom angles of 65 degrees or more, the indicated angle shall be from 1½ degrees less than to ½ degree greater than the indicated angle.

SAE J-376a, *Recommended Practice for Load Indicating Systems*, does not require maximum set points for the load, but has only audible and visible warning requirements for systems that are so equipped. Accuracy of the indicated load is required to be within -3 percent to +10 percent of the actual load, establishing limits of 3 percent overload and 10 percent underload conditions. Although not explicitly stated, accuracy of the load-warning signals is by implication the same as for the load indication.

Accuracy of Load Indicators

Table 27 summarizes the results of tests on load indicators and load warning signals. Deviations of load indication varied from -4.0 percent to +3.1 percent. Deviations of alarm signals varied from -11.1 percent to +8.1 percent. These results indicate that not all systems meet the SAE requirements at all points. Also, only two of the systems, Dillon

and Revere, showed the same deviations for both load indication and alarm activation. The Revere system, equipped with 85 percent alarm as well as 100 percent, showed complete agreement between load indication and 100 percent alarm, but the 85 percent alarm deviated considerably.

The results of the field tests on the load indicator alarm systems should be interpreted cautiously. The Forney system permits load limit settings only in increments of 1000 lb (453.59 kg). A 1 percent error in load determination could cause an *apparent* error of 11 percent in alarm signal, as indicated by the following example. At 40° boom angle, a 9000-lb (4082.31 kg) load was used. If the load determination circuitry was off by -10 lb (-4.54 kg) (about -1 percent), the alarm circuit would "see" a load of 8990 lb (4077.77 kg), and would not activate the alarm which is set at 9000 (4082.31 kg). The alarm would activate only for the next lower setting, which in this case is 8000 lb (3628.72 kg). The method of determining alarm accuracy as specified in the field test procedure was the only practical way to test the systems, as handling an actual series of loads in 100-lb (45.36 kg) increments would have been physically impossible.

Accuracy of Boom Angle Indicators

Table 28 summarizes results of tests on boom angle indicators and angle warning signals. Deviations of boom angle alarm indication and signaling varied from -4.9 degrees to +1.4 degrees; however, each indicator failed to meet the SAE requirements at only one angle, or had consistent errors which could indicate the crane was not exactly horizontal when the test was conducted.

Accuracy of Load Moment Computers

The two load moment systems tested are somewhat different in their indications. The Mark Products device (Markload System III) indicates the boom angle to the operator. The SEQ COWS device indicates the radius to the load. To put the two systems on a comparable basis, the radius determination and indication of the COWS were converted to the corresponding boom angle. Load versus angle curves were plotted for both systems, and deviations of the warning indications for the test loads from the curve were determined. The Portland District, which tested the Markload device, does not use the crane loading tables furnished by the manufacturer. Instead, they measure the actual tipping load at

various radii or boom angles, and establish their own loading curve at two thirds of those values.¹² For the purposes of the tests, they related the actual loads to this loading curve. Three of the selected loads matched 20, 40, and 80 degree angles respectively, while the fourth load corresponded to a boom angle of 62 degrees.

Table 29 presents results of the tests. For the Markload System III, the 85 percent of maximum capacity warnings deviated from the loading curve from 0.0 to +8.9 percent. The 100 percent warnings deviated from the loading curve from 0.0 to +6.5 percent. Deviation of the COWS system's actual warning from the loading curve varied from -3.9 percent to +9.2 percent of the curve.

Caution should again be used when interpreting load moment indicator alarm errors, as the same or similar factors which influenced the load indicator alarms could influence the alarm signal. At high angles, a slight error in angle determination would be reflected by a much larger error in radius calculation, resulting in a disproportionate error in load moment calculation. This effect is noticed in the Markload III test at 66 degrees.

5 CONCLUSIONS

Laboratory Tests

The functioning ability of load-, angle- or radius-, and load-moment-indicating systems was found to be satisfactory. All devices complied with the precision and accuracy requirements of the SAE-recommended practices. Devices survived temperatures of -50° to +150°F (-45.6° to 65.6°C) and relative humidities of 20 and 90 percent at 40°, 100°, and 150°F (4.4°, 37.8°, and 65.6°C). In addition to testing for compliance with SAE requirements, the following observations were made:

- a. Nine of the ten load cells tested for impact loads survived.
- b. When the systems were tested under simulated operating conditions in the laboratory, the load and

boom angle values displayed by the systems deviated consistently from the loads and boom angles actually applied to the sensors. In systems with the SAE accuracy based on percent, a constant deviation in magnitude appears to be a larger percentage error for small output magnitudes than for larger magnitudes.

c. Hydraulic load cells and pendulum boom angle sensors generally displayed increased errors at lower temperature extremes, probably due to the increase in viscosity of the fluids in the systems.

The LIDS manufacturers have no difficulty in complying with the SAE requirements' current tolerance specifications, which keep operation of a crane within safe limits. However, the precision of determination of the boom angle, even though within SAE tolerances, is not always reflected in the precision of indication to the crane operator. An SAE angle determination tolerance of 1/2 degree cannot be met by an indicator graduated in 2-degree increments; such an indicator cannot be read any more closely than 1 degree.

Field Tests

Results from the load-indicating devices are inconclusive, due to the lack of set point resolution. The load-moment computers complied with the SAE requirements and the angle indicators in general performed accurately.

Information from some of the Districts performing the tests indicated that frequent recalibration was required due to minor defects in installation or manufacturing. This indicates that the state-of-the-art of load-indicating devices may not have reached the point where standard designs show consistent performance. Tests performed with multiple parts-of-line rigging required the sheaves to be well lubricated to reduce friction. A load cell located within the structure of the crane, where it was not dependent on the tension in the lifting line, did not sense the effect of sheave friction.

Field tests also indicated that inconsistent load limit settings on the various systems can seriously affect crane operation at low boom angles (less than 20 degrees above horizontal). A load limit set at less than the load being lifted activates the alarm, while a load limit set at almost 1000 lb (453.59 kg) higher than the load being lifted could allow an unsafe condition without warning the operator.

¹²John A. Larkin, *A Review of Crane Testing Procedures in the Portland District* (Portland District, North Pacific Division, U.S. Army Corps of Engineers, October 1965).

6 RECOMMENDATIONS

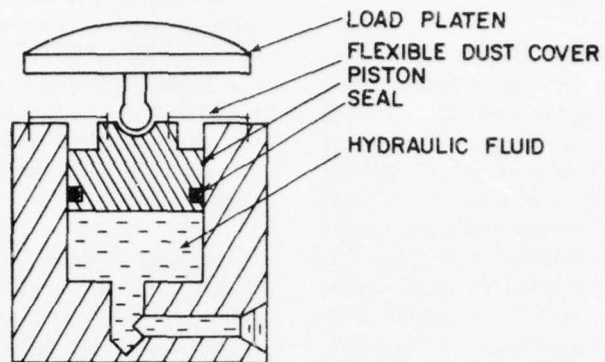
It is recommended that the SAE requirements for accuracy for load indicators and radius-of-load devices be made more stringent. Instead of allowing a 97 percent to 110 percent tolerance in loads or radius, a criterion of 97 percent to 105 percent should be applied to load indicators, and a band consisting of ± 2 percent of the maximum radius should be applied to radius-of-load indicators. The criteria should be applied over the range of capacities of the crane, as indicated on the crane load-angle or load-radius charts provided by the manufacturer.

It is recommended that the SAE Recommended Practices be amended to limit increments of maximum load settings to not over 100 lb (45.36 kg). The SAE Recommended Practices have no requirements for the increment at which maximum load or boom angle settings can be selected. Boom angle warning systems permit setting the maximum or minimum

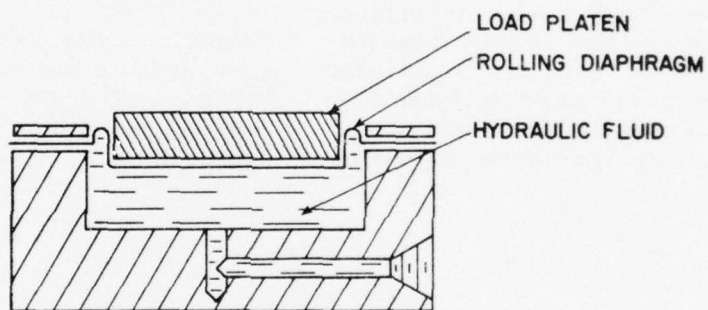
boom angle in increments of 0.1 degree. Load limit warning systems, however, are available with increments of 100 or 1000 lb (45.36 or 453.59 kg), which could lead to premature warning or an unsafe overload condition. Additional testing should be performed to determine the actual hazard present when using a LIDS with the 1000-lb (453.59 kg) increment.

It is recommended that the SAE Recommended Practices require the readout devices to display the values to the operator to the same precision as the determination. If a boom angle indicator can determine the angle of the boom to within $\frac{1}{2}$ degree, the indicator should be capable of being read to the nearest $\frac{1}{2}$ degree.

Candidate specifications for crane overload warning devices (load moment computers); crane load indicating systems; and radius of load and boom angle measuring systems are presented as Appendices G, H, and I.



a. Piston load cell.



b. Diaphragm load cell

Figure 1. Hydraulic load cells.

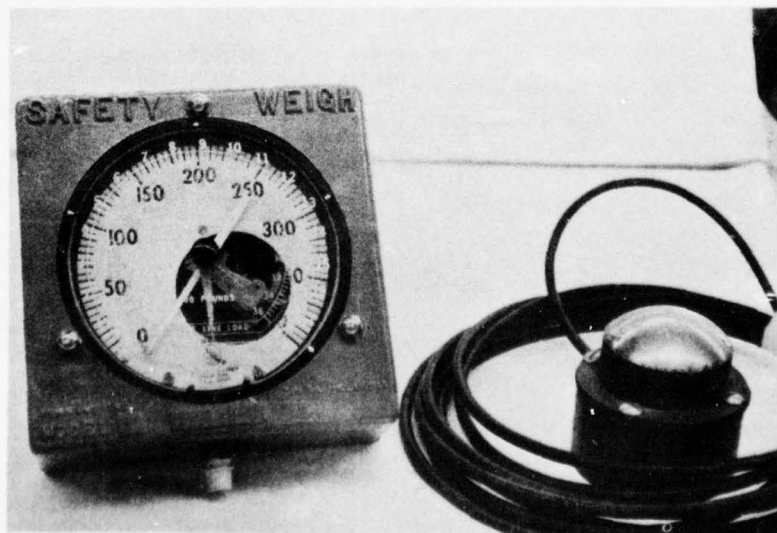


Figure 2. Pennant load indicator, model 3L-5.

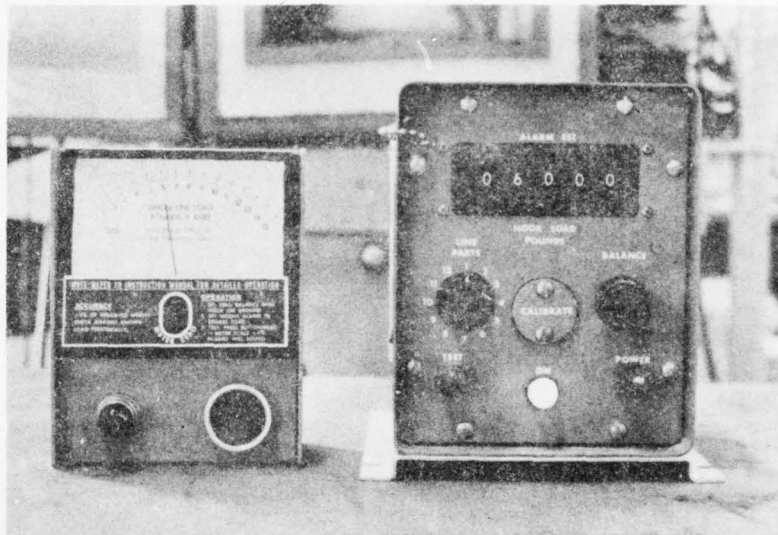


Figure 3. Eaton load indicator, model PA-181.

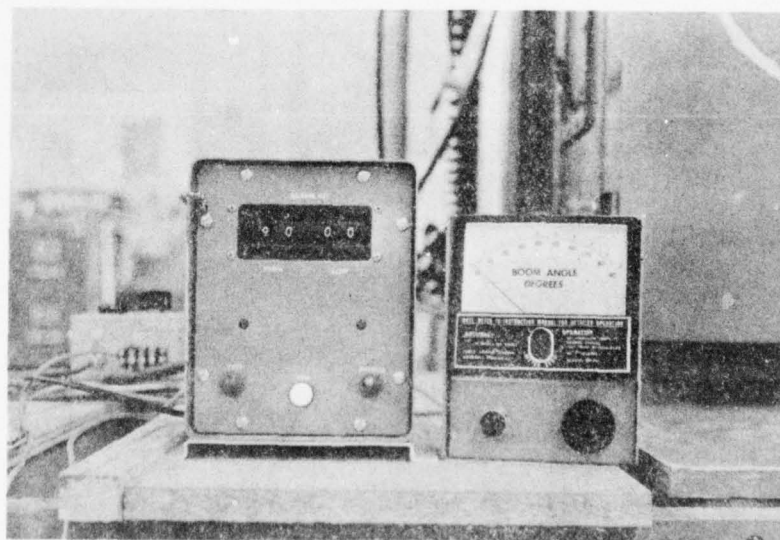


Figure 4. Eaton boom angle indicator, model PA-166.

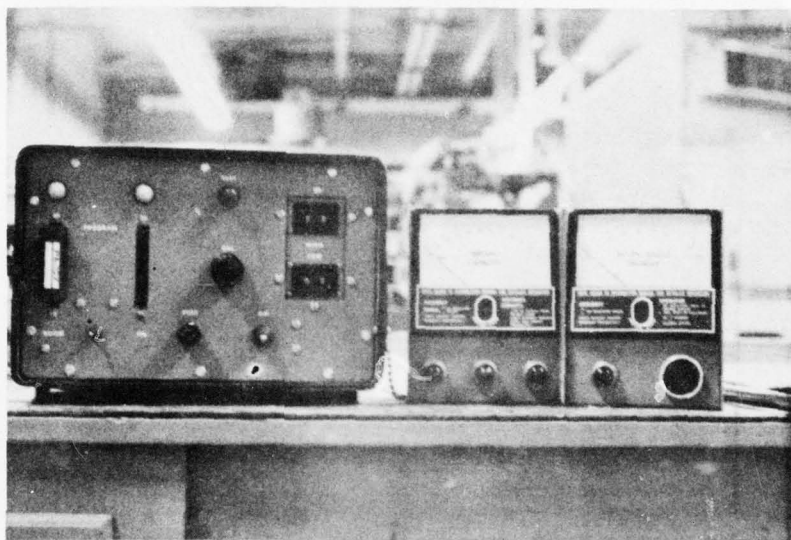


Figure 5. Eaton load moment computer, model PA-173.

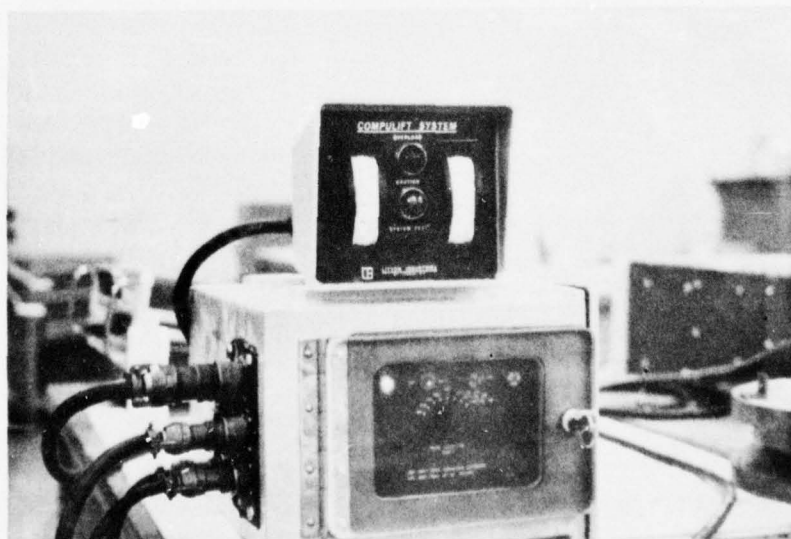


Figure 6. Litton load moment computer, model 5084.

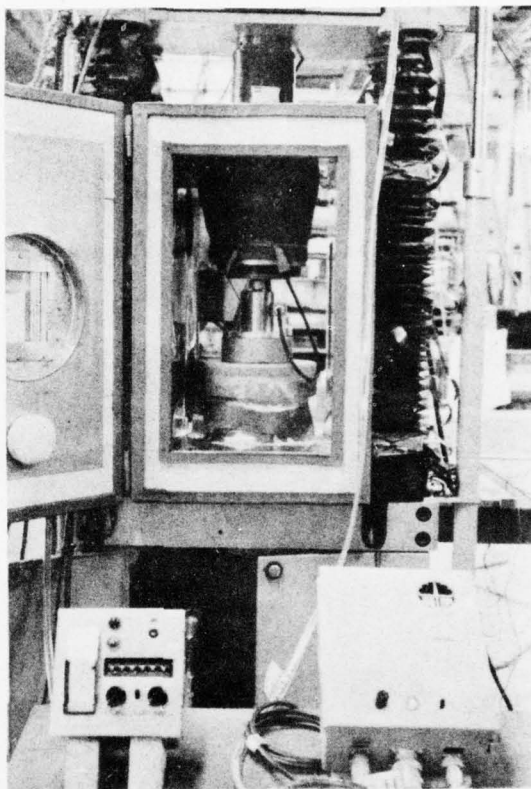


Figure 7. Typical installation of load cell.

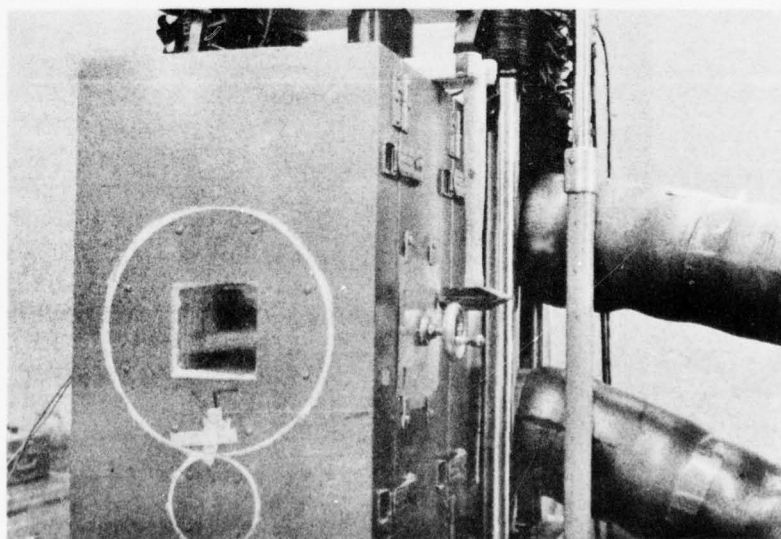


Figure 8. Handwheel to control rotary table.

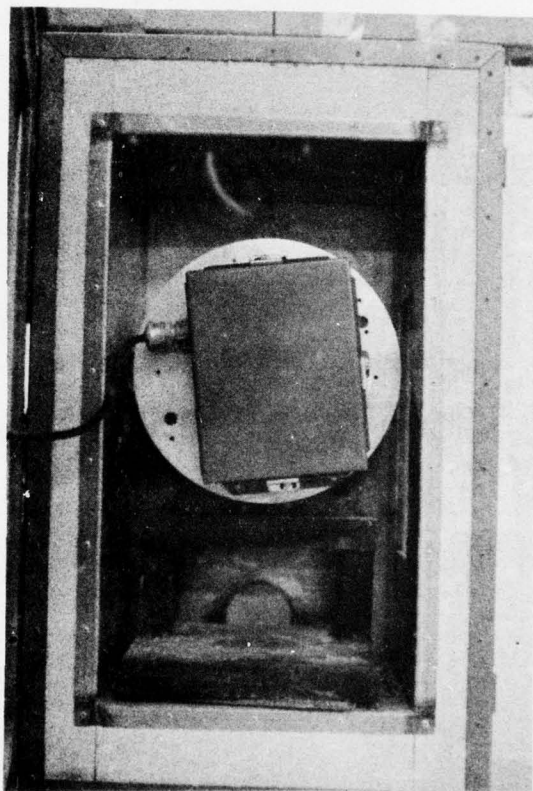


Figure 9. Typical installation of boom angle sensor.

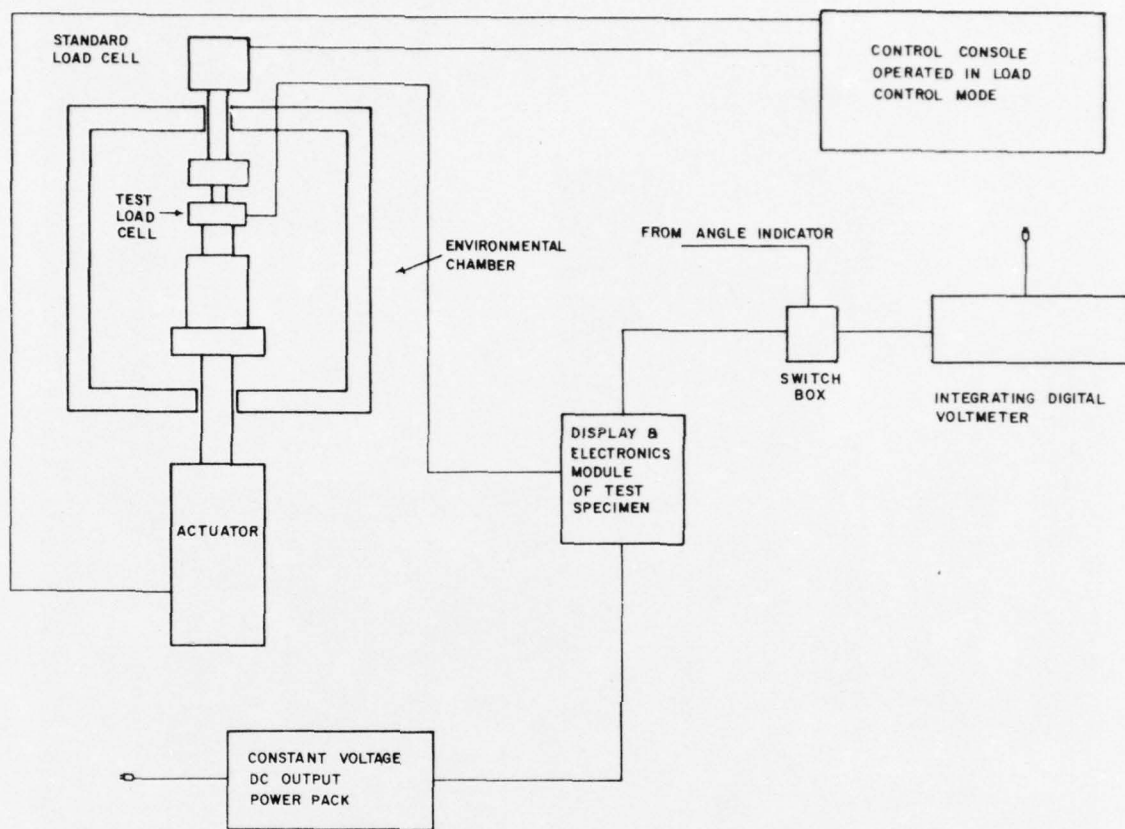


Figure 10. Typical load indicator test arrangement.

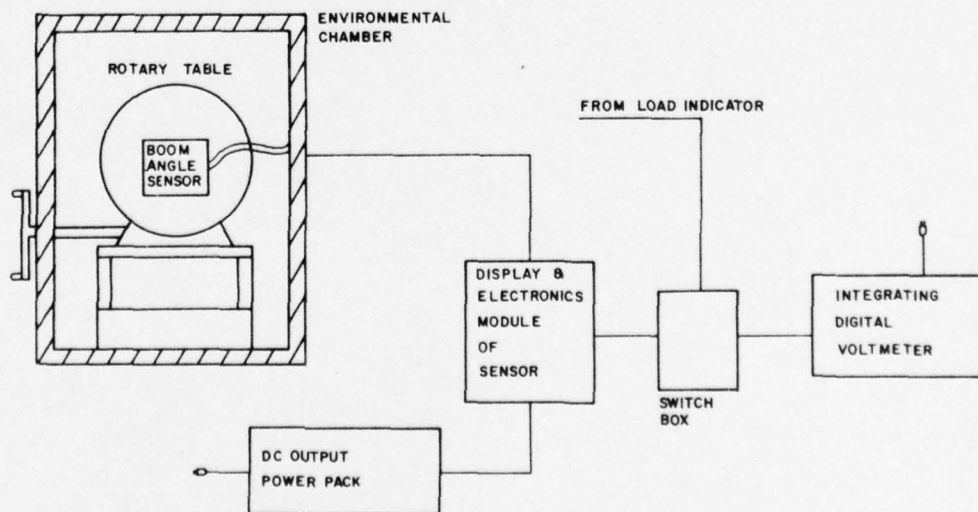


Figure 11. Typical boom angle indicator test arrangement.

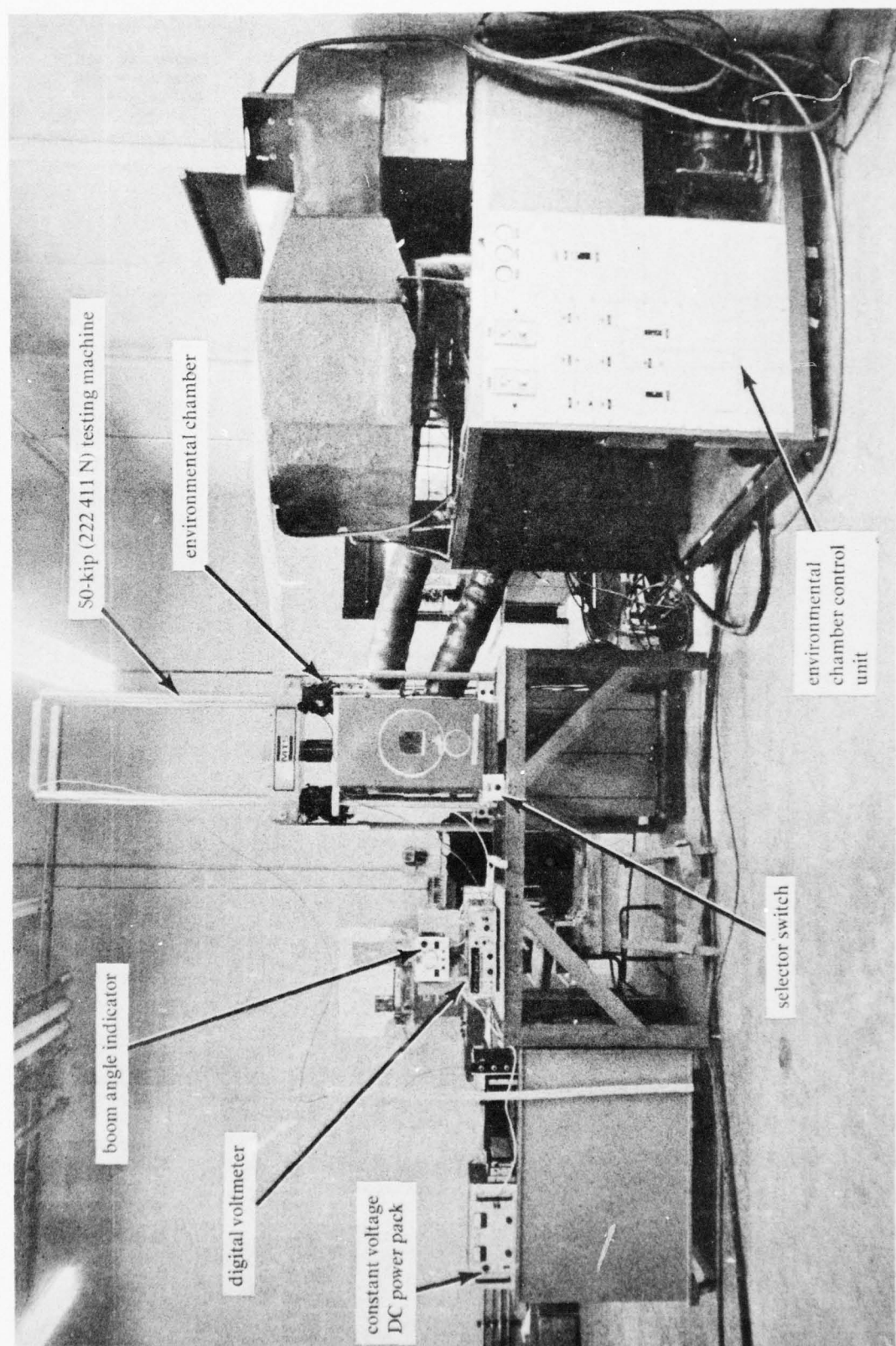


Figure 12. Equipment for laboratory testing of LIDS.

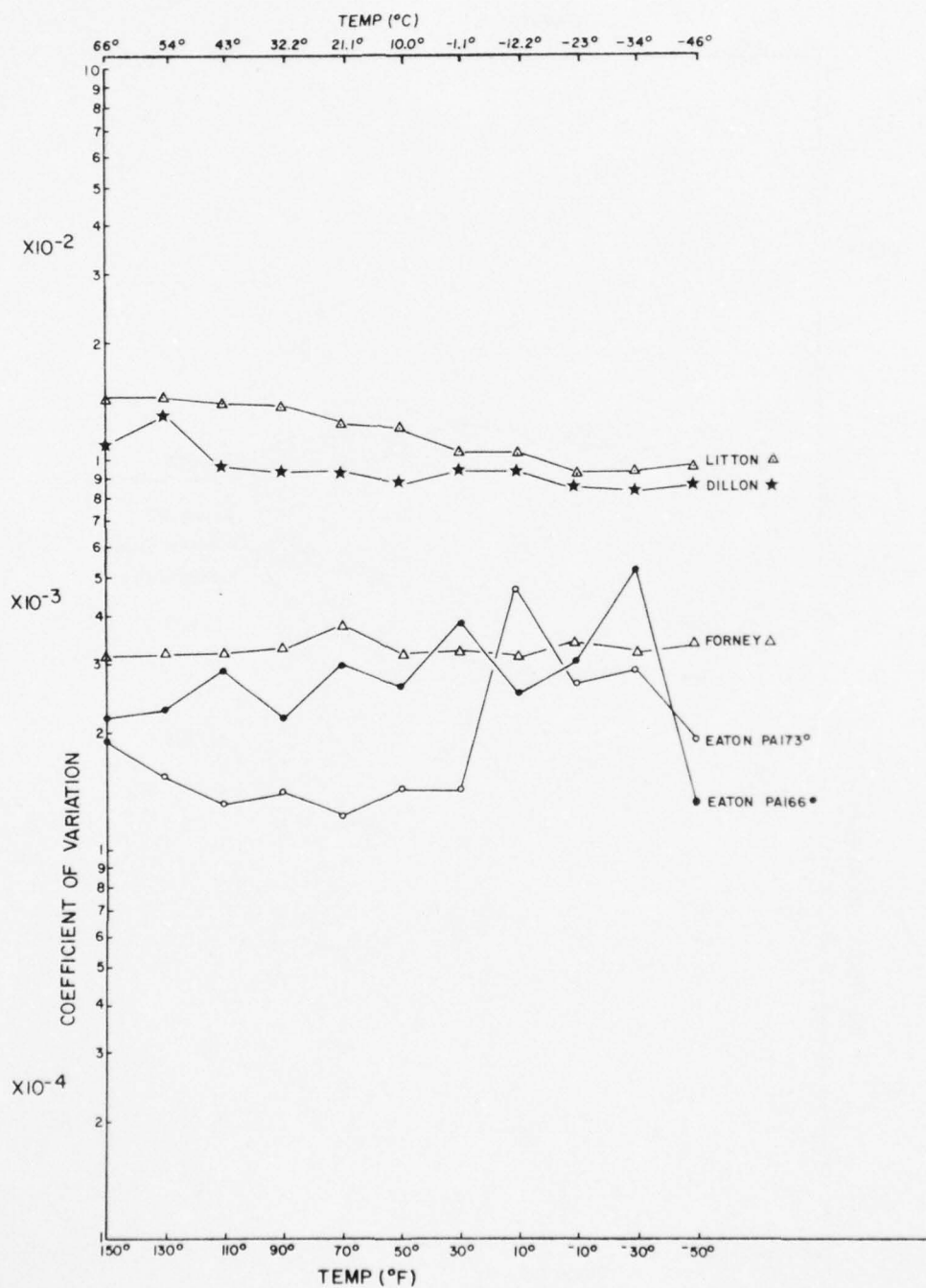


Figure 13. Load cell coefficient of variation versus temperature.

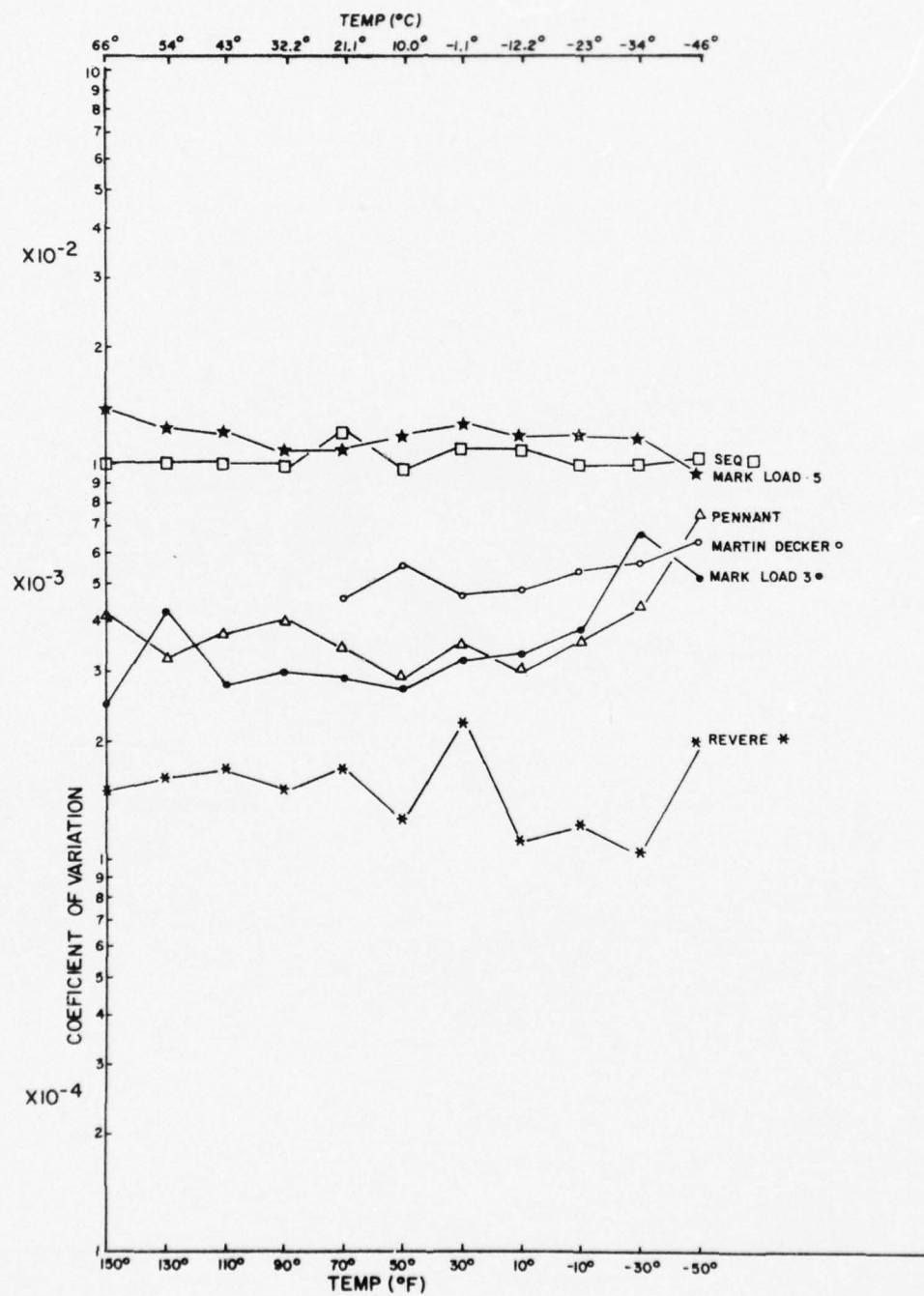


Figure 13 (cont'd.).

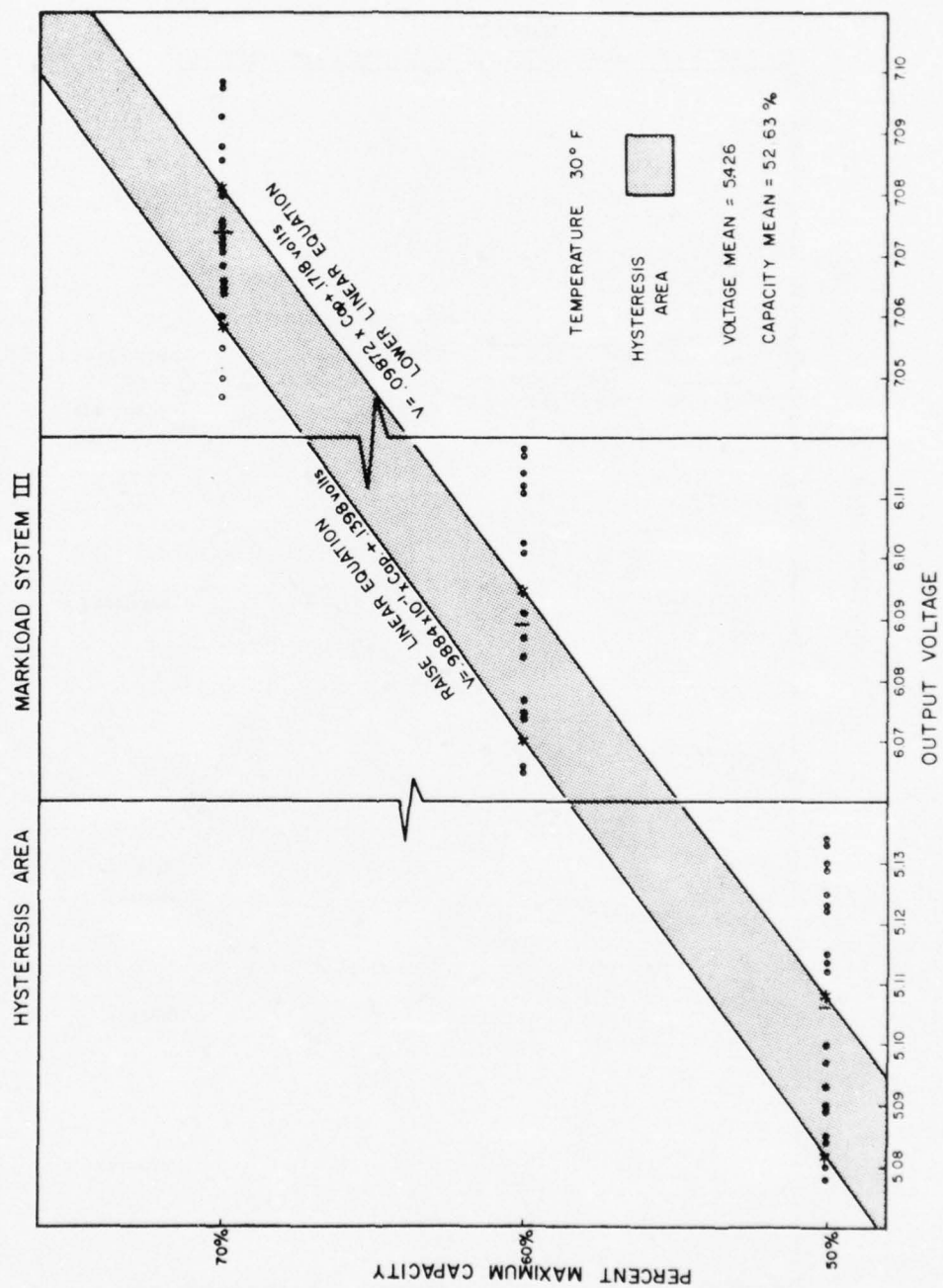


Figure 14. Hysteresis area for Markload System III.

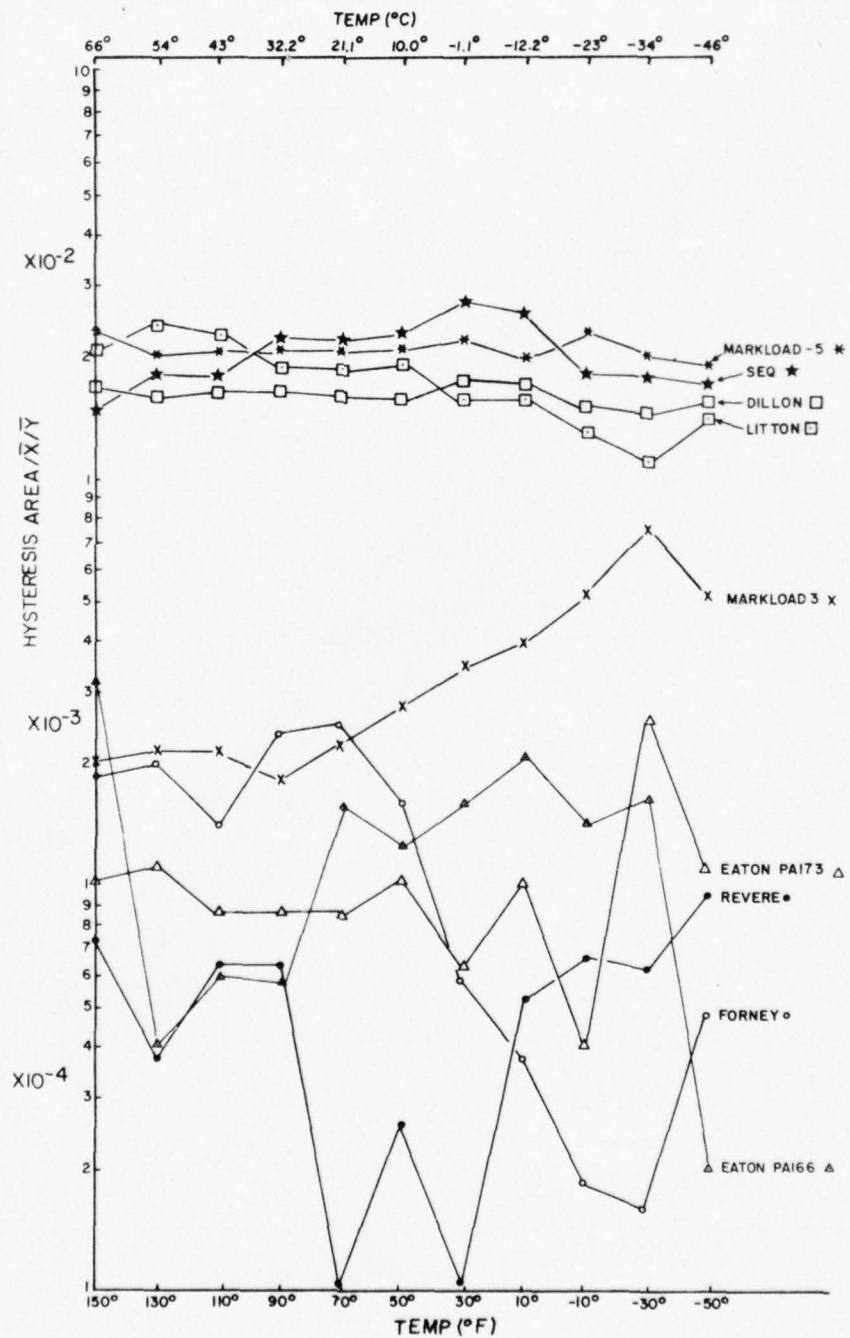


Figure 15. Hysteresis factor of LIDS versus temperature.

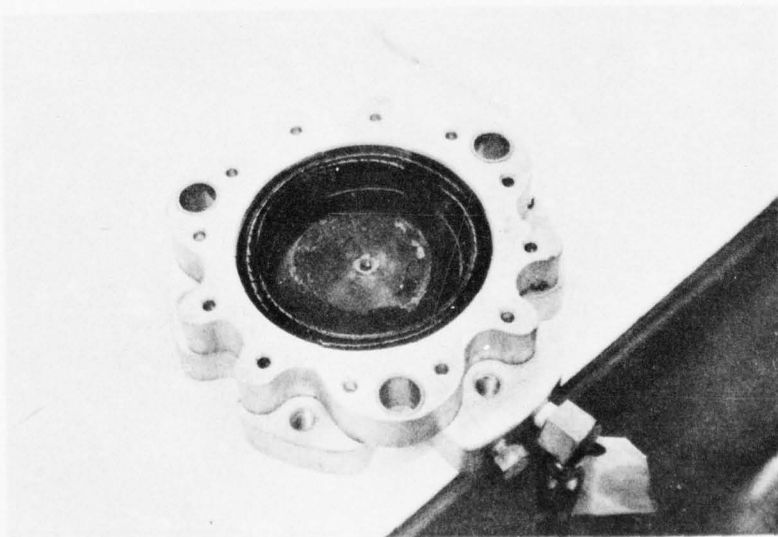
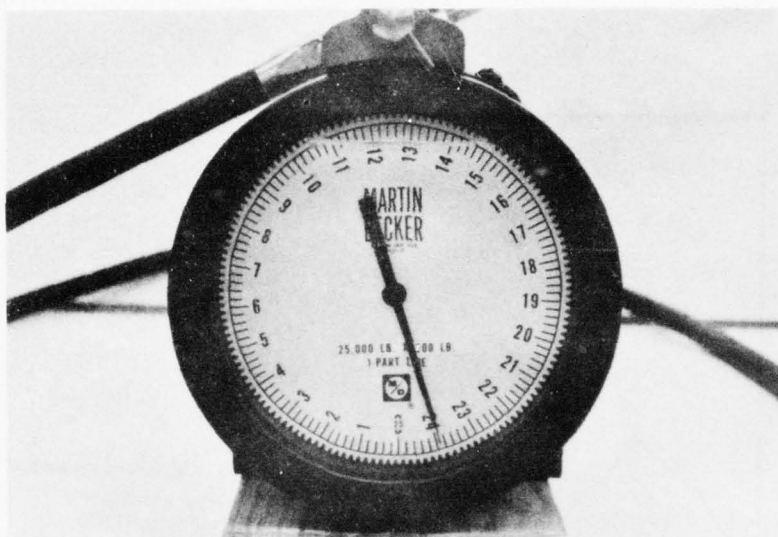


Figure 16. Martin-Decker model SC-7 load indicator and load cell with ruptured diaphragm.

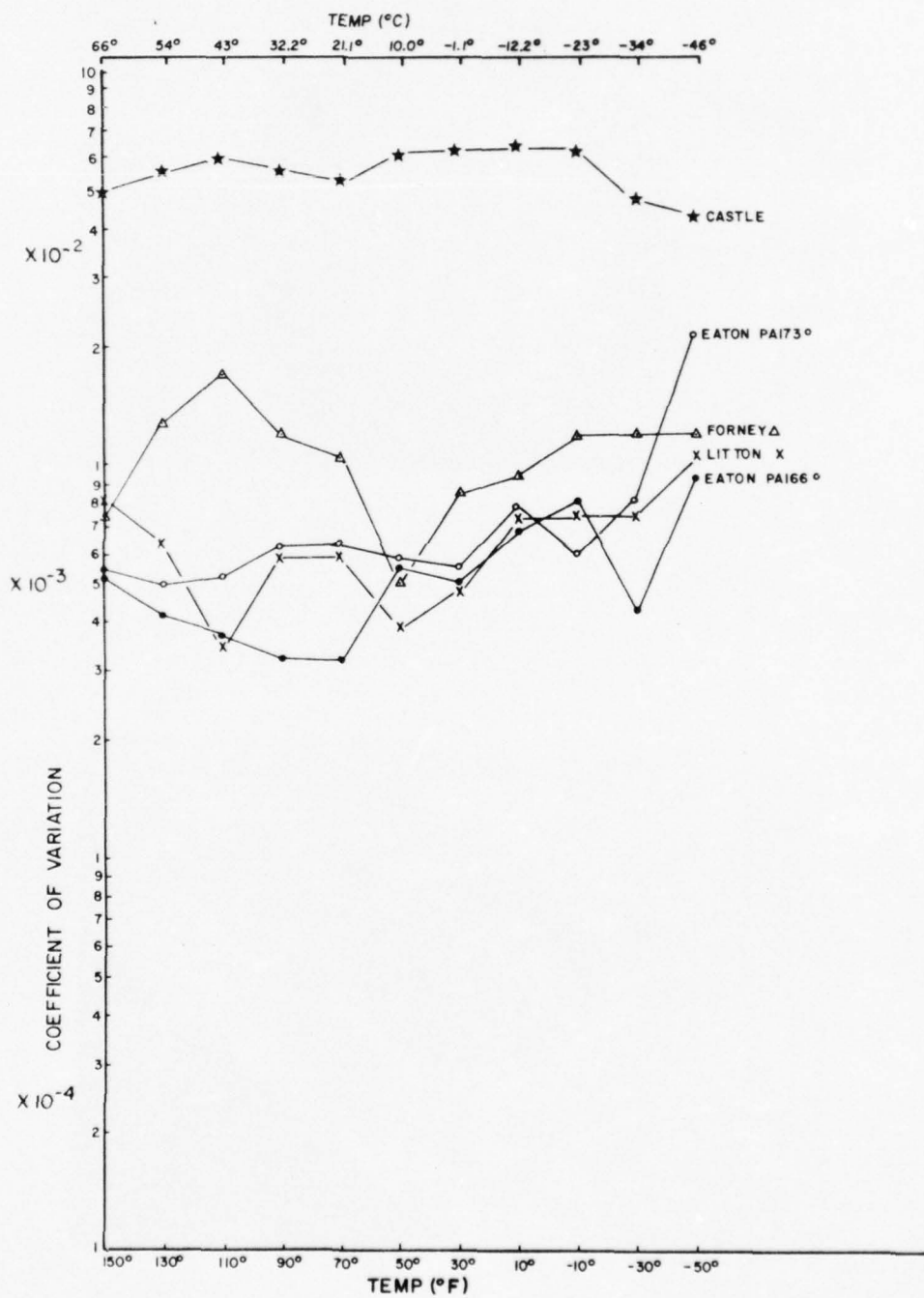


Figure 17. Boom angle coefficient of variation versus temperature.

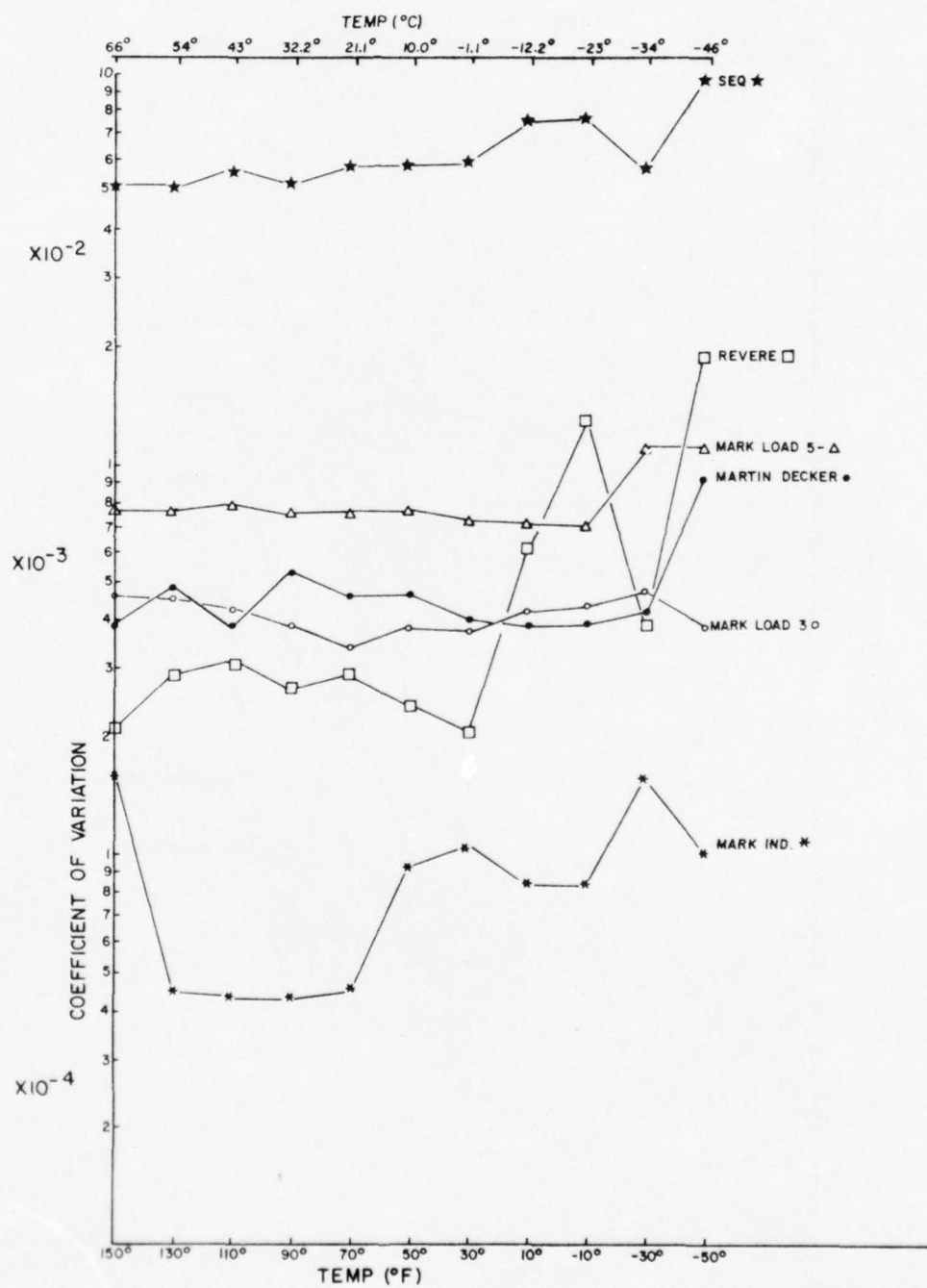


Figure 17 (cont'd).

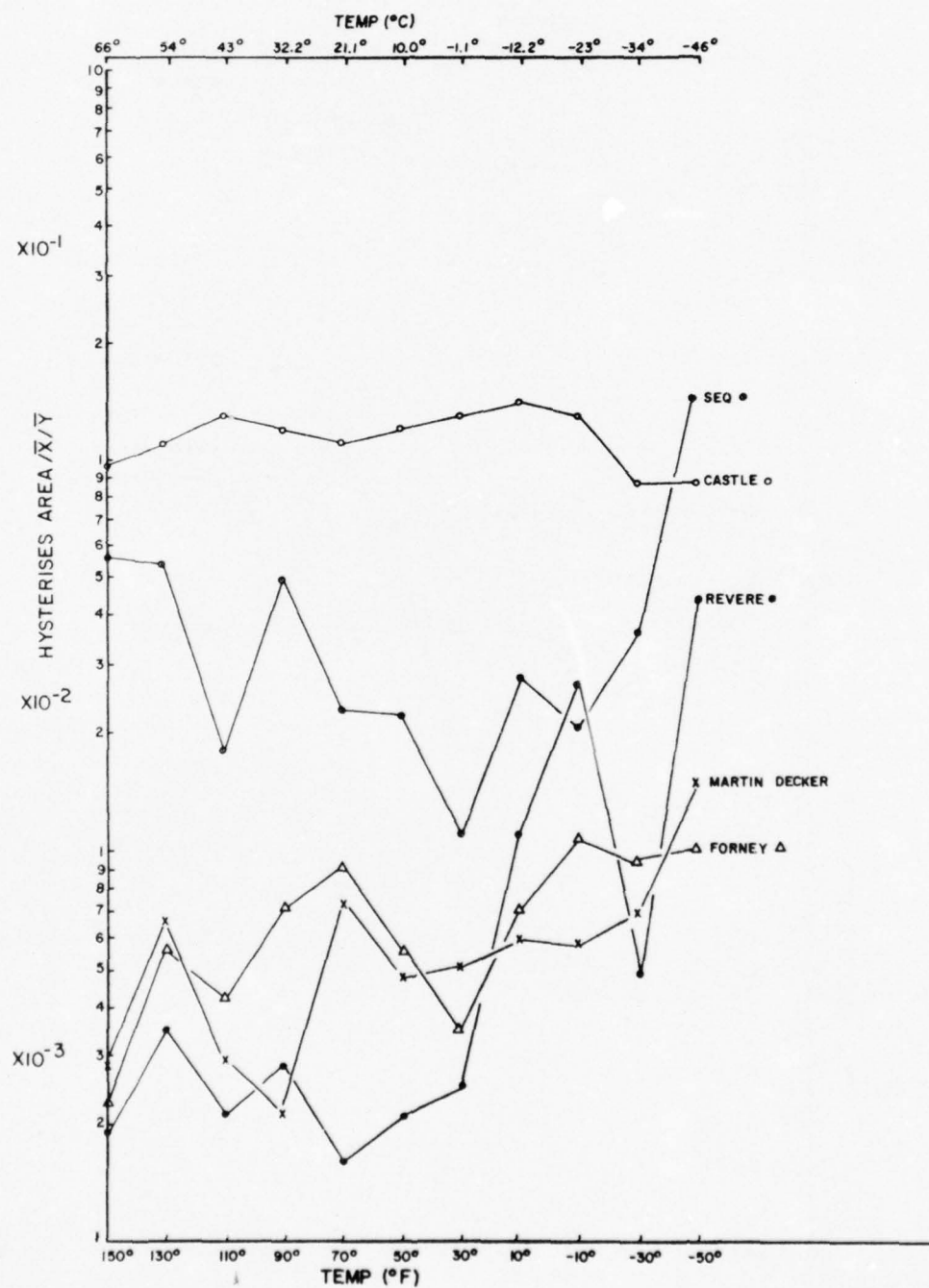


Figure 18. Hysteresis factor for boom angle indicators.

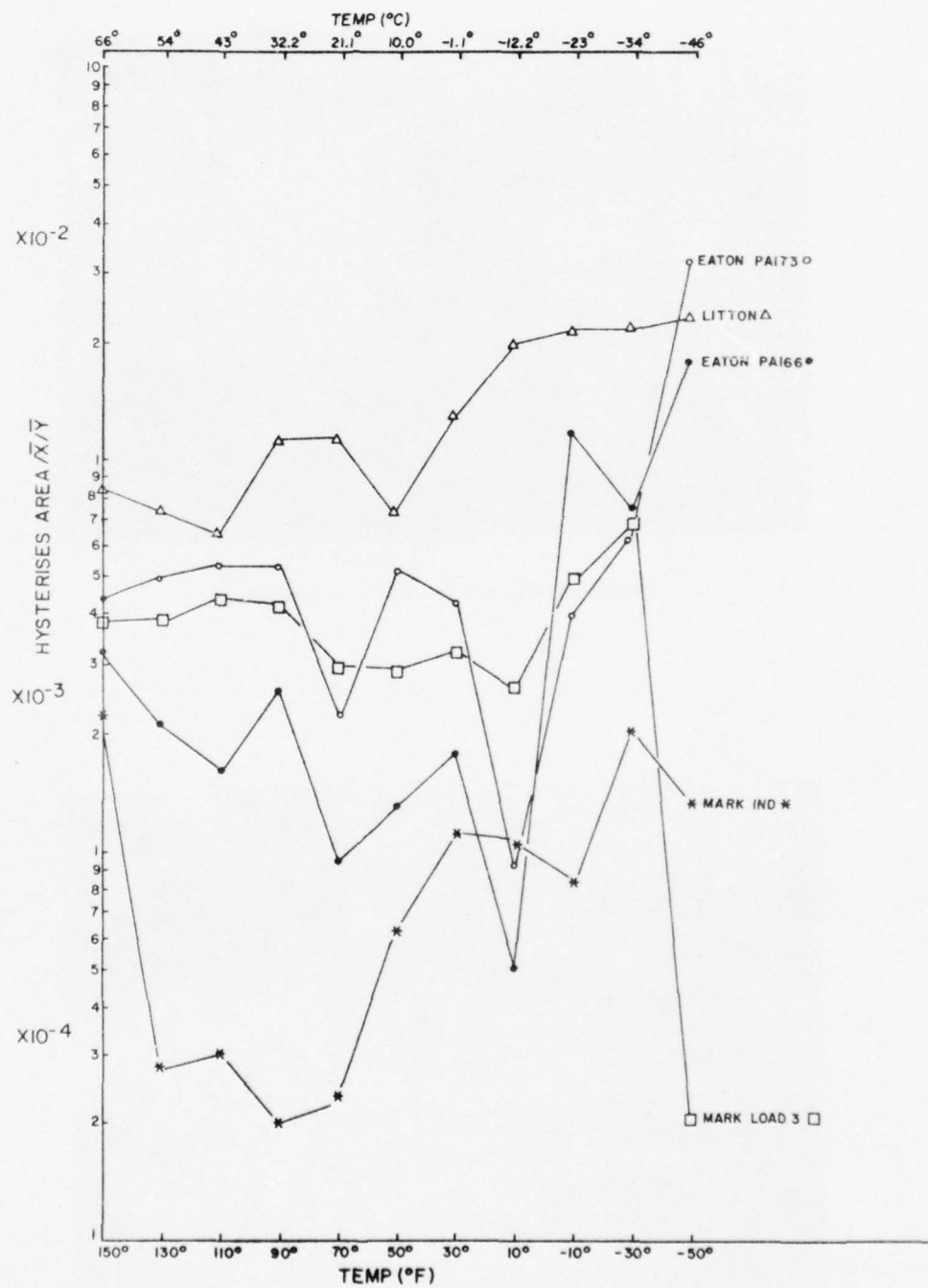


Figure 18 (cont'd).

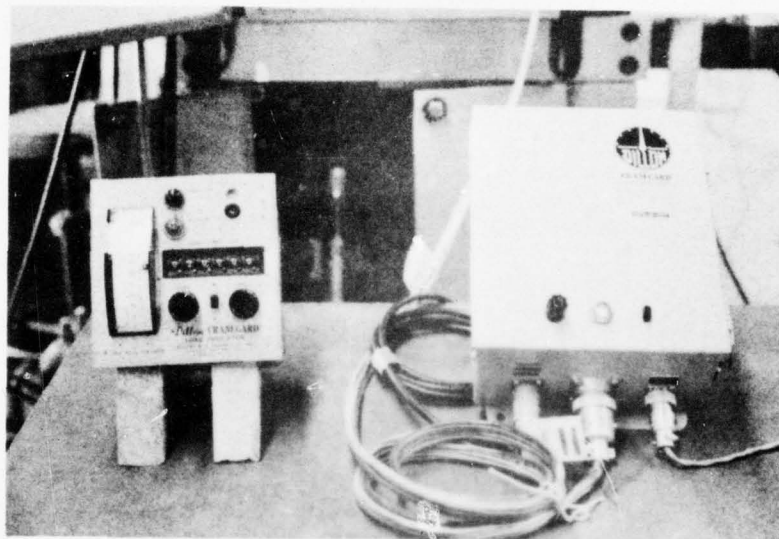


Figure 19. Dillon model LI-1, load indicator.

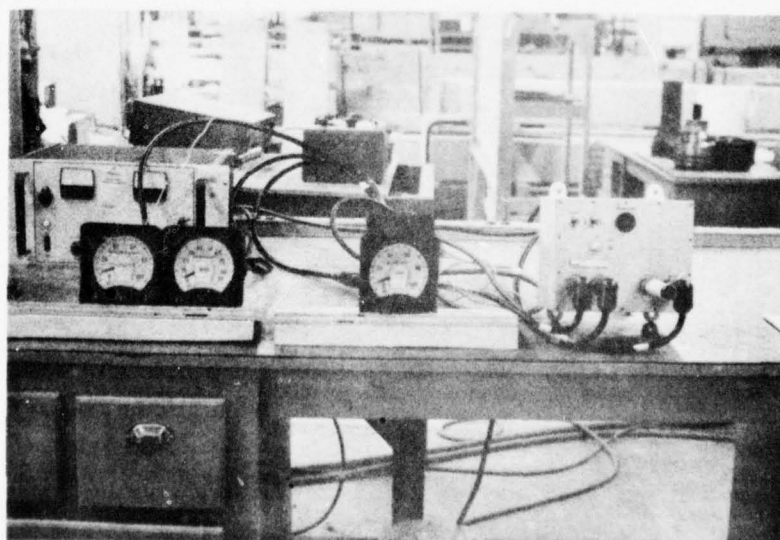


Figure 20. Mark Products System III, load moment computer.

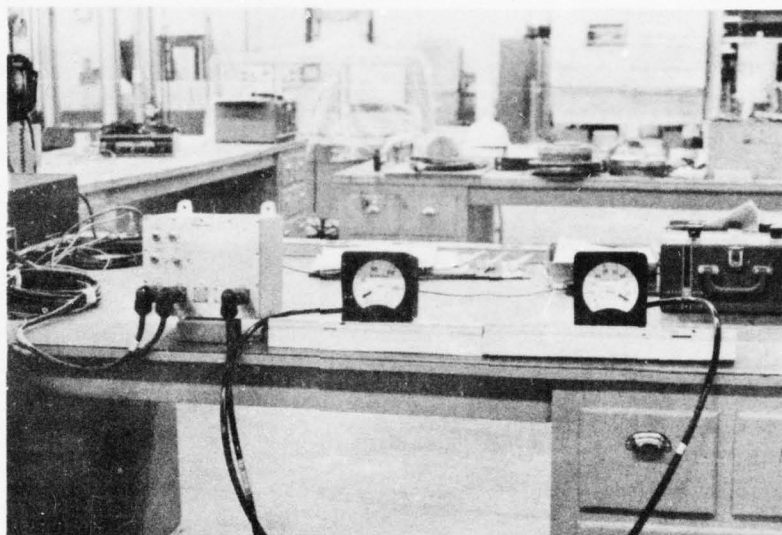


Figure 21. Mark Products System V, load and angle indicator.

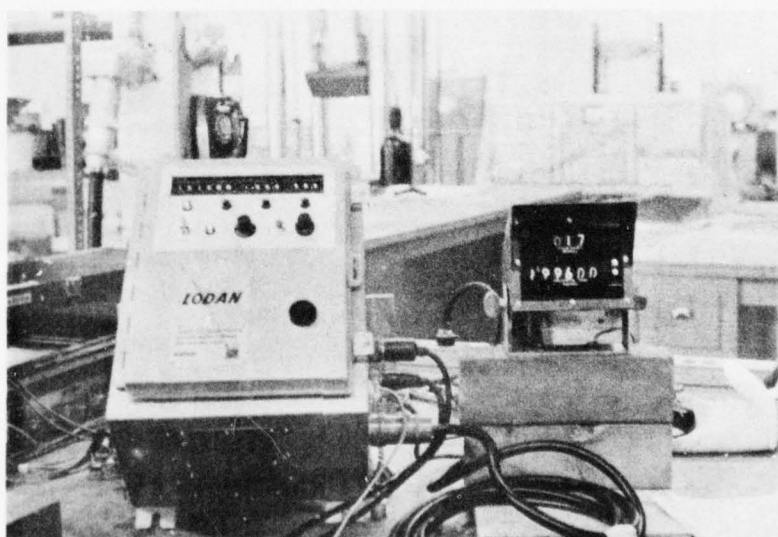


Figure 22. Revere model R-899, load indicator.

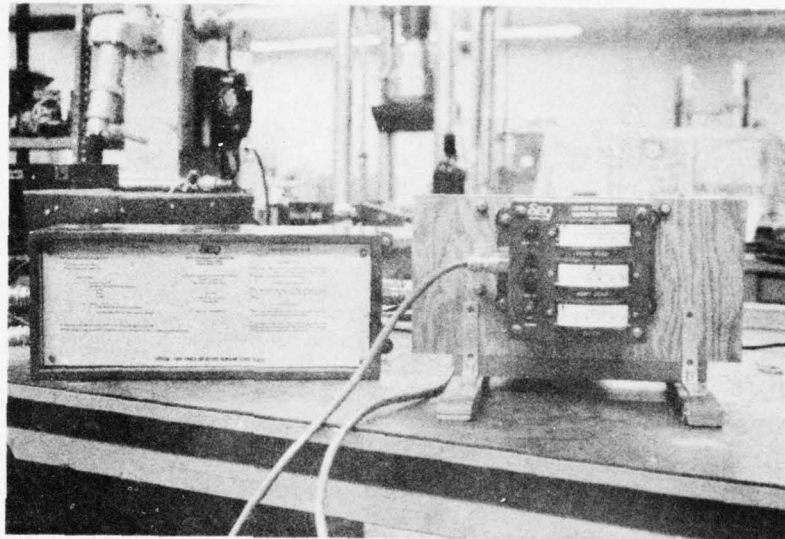


Figure 23. SEQ model COWS, load moment computer.

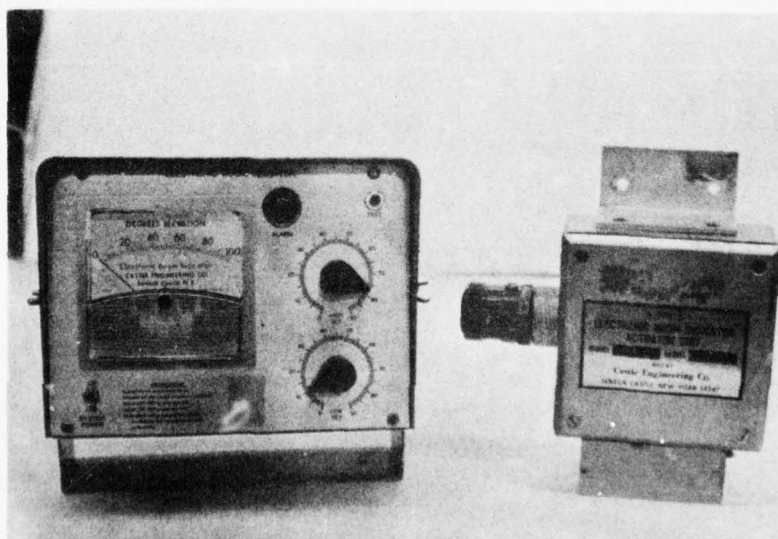


Figure 24. Castle model 154, boom angle indicator.

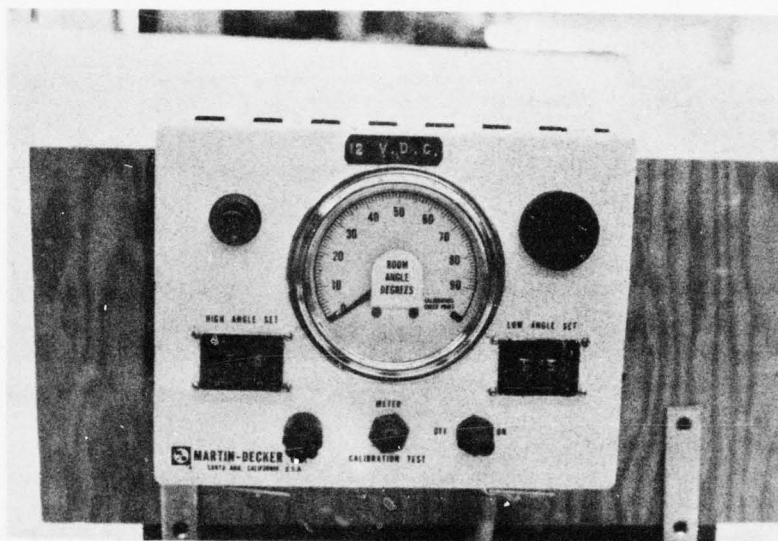


Figure 25. Martin-Decker model ECA, boom angle indicator.



Figure 26. Mark Indicator model XV, boom angle indicator.

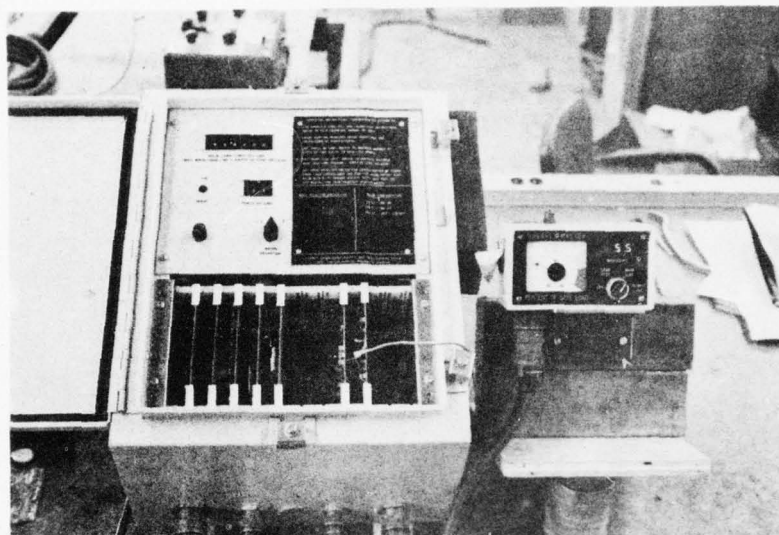


Figure 27. Forney System 20, load moment computer.

Table I
LIDS Tested in the Laboratory

Mfr**	Model	Type	Operation	Warnings	Operational Limits as Specified by Mfr	
					Mln °F (°C)	Max °F (°C)
Castle	154	angle	electronic	yes	NS*	NS
Dillon	LI-1	load	electronic	yes	-20(-28.9)	+125(51.7)
Eaton	PA-181	load	electronic	yes	-20(-28.9)	+120(48.9)
Eaton	PA-166	angle	electronic	yes	-20(-28.9)	+120(48.9)
Eaton	PA-173	computer	electronic	yes	-20(-28.9)	+120(48.9)
Forney	20	computer	electronic	yes	-20(-28.9)	+130(54.4)
Litton	5084	computer	electronic	yes	-40(-40)	+140(60)
Mark Indicator	XV	angle	electronic	yes	-20(-28.9)	+125(51.7)
Mark Products	III	computer	electronic	yes	-40(-40)	+160(71.1)
Mark Products	V	load-angle	electronic	yes	-40(-40)	+160(71.1)
Martin-Decker	SC7	load	hydraulic	no	-50(-45.6)	+150(65.6)
Martin-Decker	ECA	angle	electronic	yes	NS	NS
Pennant	3L-5	load	hydraulic	no	NS	NS
Revere	R-899	load-angle	electronic	yes	-20(-28.9)	+120(48.9)
SEQ	COWS	computer	electronic	yes	NS	NS

*NS - not specified

**Complete name and address of each manufacturer as follows:

Castle Engineering Company
P.O. Box 154
Seneca Castle, NY 14547

Litton Industries, Potentiometer Div.
226 East Third St.
Mt. Vernon, NY 10550

Pennant, Inc.
P.O. Box 3656
Tulsa, OK 74152

W. C. Dillon & Co., Inc.
14620 Keswick St.
Van Nuys, CA 91407

Mark Indicator Co., Inc.
P.O. Box 70
Easton, PA 18042

Revere Corp. of America
845 North Colony Rd.
Wallingford, CT 06492

Eaton Corp., Controls Div.
191 E. North Ave.
Carol Stream, IL 60187

Mark Products, Inc.
10507 Kinghurst Dr.
Houston, TX 77072

Systems Equipment, Inc. (SEQ)
P.O. Box 58841
Houston, TX 77058

Forney Engineering Co.
P.O. Box 189
Addison, TX 75001

Martin-Decker Co.
1928 South Grand Ave.
Santa Ana, CA 92705

Table 2
LIDS Tested in the Field

Mfr	Model	Type	Operation	Warnings	Remarks
Dillon	E	load	electronic	yes	Vicksburg District, Little Giant model 48 motor crane, with 40-ft (12.19 m) boom
Dillon	D	angle	electronic	yes	Vicksburg District, Little Giant model 48 motor crane, with 40-ft (12.19 m) boom
Eaton	PA-181	load	electronic	yes	New Orleans District, Bucyrus-Erie model 38-B crane with 75-ft (22.86 m) boom, mounted on a barge
Eaton	PA-166	angle	electronic	yes	New Orleans District, Bucyrus-Erie model 38-B crane with 75-ft (22.86 m) boom, mounted on a barge
Forney	SL	load	electronic	yes	Vicksburg District, Thew-Lorain model 320
Mark Products	III	computer	electronic		Portland District, Northwest 35-ton (31 751 kg) truck crane, model 41, with 50-ft (15.24 m) boom and 20-ft (6.10 m) jib
Martin-Decker	SD-12-500	load	hydraulic	no	Louisville District, Clyde Whirley model LD-646, 25-ton (22 680 kg), with 70-ft (21.34 m) boom
Revere	R-900	load-angle	electronic	yes	St. Louis District, Lorain model 330 moto crane
SEQ	COWS	computer	electronic	yes	New Orleans District, Bucyrus-Erie model 38-B series 2 crawler crane with 90-ft (27.43 m) boom

Table 3
Percent Variation From Actual Load for Dillon Model LI-1

Load Meter	Percent Maximum Load									
	10	20	30	40	50	60	70	80	90	100
Temp. -50°F (-45.6°C)										
Humid. —										
Raising	+4	+3	+2	+1	+1	+1	+1	0	0	0
Lowering	+4	+3	+2	+1	+1	0	0	0	0	0
Temp. 40°F (4.4°C)										
Humid. 20%										
Raising	+3	+2	+2	+1	+1	+1	+1	+1	0	0
Lowering	+3	+2	+2	+1	+1	+1	0	0	0	0
Temp. 40°F (4.4°C)										
Humid. 90%										
Raising	+3	+3	+3	+2	+2	+2	+1	+1	+1	+1
Lowering	+3	+3	+2	+2	+1	+1	+1	+1	+1	+1
Temp. 70°F (21.1°C)										
Humid. —										
Raising	0	+2	+2	+1	+1	+1	+1	+1	0	0
Lowering	0	+2	+2	+1	+1	+1	0	0	0	0
Temp. 100°F (37.8°C)										
Humid. 20%										
Raising	+4	+4	+3	+3	+2	+2	+2	+2	+1	+1
Lowering	+4	+3	+3	+2	+2	+2	+2	+1	+1	+1
Temp. 100°F (37.8°C)										
Humid. 90%										
Raising	+3	+3	+3	+2	+2	+2	+2	+1	+1	+1
Lowering	+3	+3	+3	+2	+2	+2	+2	+1	+1	+1
Temp. 150°F (65.6°C)										
Humid. —										
Raising	+3	+3	+2	+2	+1	+1	+1	0	0	0
Lowering	+3	+2	+2	+1	+1	+1	0	0	0	0

Table 4
Percent Variation From Actual Load for Eaton Model PA-181

Load Meter	Percent Maximum Load									
	10	20	30	40	50	60	70	80	90	100
Temp. -50°F (-45.6°C)										
Humid. —										
Raising	0	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	0	—
Temp. 40°F (4.4°C)										
Humid. 20%										
Raising	0	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	0	0
Temp. 40°F (4.4°C)										
Humid. 90%										
Raising	0	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	0	0
Temp. 70°F (21.1°C)										
Humid. —										
Raising	0	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	0	0
Temp. 100°F (37.8°C)										
Humid. 20%										
Raising	0	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	0	0
Temp. 100°F (37.8°C)										
Humid. 90%										
Raising	0	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	0	0
Temp. 150°F (65.6°C)										
Humid. —										
Raising	0	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	0	0

Table 5
Percent Variation From Actual Load for Mark Products System III

Load Meter	Percent Maximum Load							
	10	12.6	16	20.7	26.9	35.5	57	90
Temp. -50°F (-45.6°C)								
Humid. —								
Raising	+ 7.5	+3	+2	+5	+4	+3	+ .5	— .5
Lowering	+ 7.5	+8	+2	+5	+4	+2	+ .5	0
Temp. 40°F (4.4°C)								
Humid. 20%								
Raising	+ 8	+7	+5	+5	+4	+3	+1	0
Lowering	+ 8	+8	+7.5	+7	+6	+4	+1.5	0
Temp. 40°F (4.4°C)								
Humid. 90%								
Raising	+ 8	+9	+6	+6	+4	+4	+1	0
Lowering	+10	+9	+7	+7	+6	+4	+2	0
Temp. 70°F (21.1°C)								
Humid. —								
Raising	+10	+9	+3	+6	+5	+4	+2	+ .5
Lowering	+11	+9	+3	+6	+5.5	+4	+2	+ .5
Temp. 100°F (37.8°C)								
Humid. 20%								
Raising	+ 5	+7	+3	+4	+3	+3	+ .5	0
Lowering	+10	+9	+6	+6	+5	+4	+1.5	0
Temp. 100°F (37.8°C)								
Humid. 90%								
Raising	+ 8	+3	+5	+5	+4	+3	+1	0
Lowering	+ 8	+2	+6	+6	+5	+4	+1	0
Temp. 150°F (65.6°C)								
Humid. —								
Raising	0	+3	0	+ .5	+1	+3	-1	— .5
Lowering	+ 2	+3	+2	+4	+2	+1.5	0	— .5

Table 6
Percent Variation From Actual Load for Mark Products System V

Load Meter	Percent Maximum Load									
	10	20	30	40	50	60	70	80	90	100
Temp. -50°F (-45.6°C)										
Humid. —										
Raising	-8	0	-1.5	-1	-2	-2	-1	-1.5	-1	—
Lowering	-8	0	0	0	0	0	0	0	-1	
Temp. 40°F (4.4°C)										
Humid. 20%										
Raising	0	+ 4	+1	+1	+1	0	+ .5	0	0	—
Lowering	0	+ 6	+4	+4	+1	+ .5	+1	+ .5	0	
Temp. 40°F (4.4°C)										
Humid. 90%										
Raising	0	+ 2	+1	+1	0	0	+ .5	+ .5	0	—
Lowering	0	+ 4	+3	+2	+1	+ .5	+1	+ .5	0	
Temp. 100°F (37.8°C)										
Humid. 20%										
Raising	0	+ 6	+4	+2	+1	+1	+ .5	+ .5	0	—
Lowering	+4	+10	+5	+4	+1.5	+1	+ .5	+1	0	
Temp. 100°F (37.8°C)										
Humid. 90%										
Raising	0	+ 6	+4	+2	1	+ .5	+ .5	+ .5	0	—
Lowering	0	+10	+5	+5	+1.5	+1	+1	+1	0	
Temp. 150°F (65.6°C)										
Humid. —										
Raising	+8	+10	+4	+3	+1.5	+ .5	+1	+1	0	—
Lowering	+8	+10	+5	+5	+1.5	+2	+1.5	+1	0	

Table 7
Percent Variation From Actual Load for Pennant Model 3L-5

Load Meter	Percent Maximum Load									
	10	20	30	40	50	60	70	80	90	100
Temp. -50°F (-45.6°C)										
Humid. —										
Raising	-22	-16	-14	-12	-10	-8	-8.5	-8	-8	-8
Lowering	-17	-15	-12	-8	-8	-7	-7.5	-8	-7	-8
Temp. 40°F (4.4°C)										
Humid. 20%										
Raising	-5	-5	-6.5	-5.5	-4	-4	-4.5	-4.5	-4	-4.5
Lowering	0	-5	-6.5	-4	-4	-4	-4.5	-4	-4	-4.5
Temp. 40°F (4.4°C)										
Humid. 90%										
Raising	-11	-11	-8	-8	-6	-6	-5.5	-5.5	-5.5	-5
Lowering	-11	-11	-7.5	-7	-5.5	-5	-5	-5	-5	-5
Temp. 70°F (21.1°C)										
Humid. —										
Raising	-5	-8	-7.5	-5.5	-5	-4	-4	-4	-4	-4.5
Lowering	-5	-8	-7.5	-5	+4.5	-4	-4	-3.5	-4	-4.5
Temp. 100°F (37.8°C)										
Humid. 20%										
Raising	0	-4	-4	-4	-3	-3	-3	-3.5	-4	-3
Lowering	0	-3	-4	-2	-2	-2	-2.5	-3	-3	-3
Temp. 100°F (37.8°C)										
Humid. 90%										
Raising	-5.5	-5.5	-5	-5	-4.5	-4	-4	-4	-4	-4
Lowering	0	-5.5	-5	-3.5	-3	-3	-3	-3.5	-3.5	-4
Temp. 150°F (65.6°C)										
Humid. —										
Raising	-3	-5	-5.5	-3.5	-4	-4	-3.5	-4	-4	-3
Lowering	-3	-5	-5	-3	-3.5	-3	-3	-3	-3	-3

Table 8
Percent Variation From Actual Load for Revere Model R-899

Load Meter	Percent Maximum Load									
	10	20	30	40	50	60	70	80	90	100
Temp. -50°F (-45.6°C)										
Humid. —										
Raising	-4	-4	+ 1	-1	-1	-1	-1	-1	-1	-1
Lowering	-4	-2	0	-2	-1	-1.5	-1	-1	-1	-1.5
Temp. 40°F (4.4°C)										
Humid. 20%										
Raising	0	+2	0	0	0	0	-.5	-1	-1	-1
Lowering	0	+2	0	0	0	-.5	-.5	-1	-1	-1
Temp. 40°F (4.4°C)										
Humid. 90%										
Raising	0	+2	+1.5	0	0	0	-.5	-1	-1	-1.5
Lowering	0	+2	+1.5	0	0	0	0	-.5	-1	-1.5
Temp. 70°F (21.1°C)										
Humid. —										
Raising	-4	+4	+1.5	-1	-1	-.5	-.5	-1	-1	-1.5
Lowering	-4	+2	0	0	0	-.5	-1	-1.5	-1	-1.5
Temp. 100°F (37.8°C)										
Humid. 20%										
Raising	0	+2	+1.5	0	0	0	-.5	-2	-2	-3
Lowering	0	+2	+1.5	0	0	0	-.5	-2	-2	-3
Temp. 100°F (37.8°C)										
Humid. 90%										
Raising	0	+2	+1.5	0	0	0	0	-.5	-.5	-3
Lowering	0	+2	+1.5	0	0	0	0	-.5	-.5	-1
Temp. 150°F (65.6°C)										
Humid. —										
Raising	-4	+2	+1.5	0	+1	0	0	0	-.5	-1
Lowering	0	+2	+1.5	+1	+1	0	0	0	-.5	-1

Table 9
Percent Variation From Actual Load for SEQ Model COWS

Load Meter	Percent Maximum Load								
	50	50.9	52	53.9	56.5	60	66.75	79	97.5
Temp. -50°F (-45.6°C)									
Humid. —									
Raising	+1	+1	+1	+1	+1	0	+ .5	- .5	-1.5
Lowering	+4	+4	+4	+4	+3.5	0	+2	+2	- .5
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising	+1	0	+1	0	+1	0	- .5	- .5	- .5
Lowering	+6	+6	+6	+6	+5	+5	+3.5	+2.5	+ .5
Temp. 40°F (4.4°C)									
Humid. 90%									
Raising	+1	0	+1	0	0	+1	+ .5	0	- .5
Lowering	+6	+6	+6	+6	+5	+5	+5	+3	+ .5
Temp. 70°F (21.1°C)									
Humid. —									
Raising	+1	+1	+1	+1	+1	+1	+1	-1	-2
Lowering	+1	+2	+1	+1	+2	+1	+1	0	-2
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising	-1	+2	+1	+1	-1	0	- .5	-1	-2
Lowering	+3	+4	+4	+3	+3.5	+2.5	+2.5	+1	0
Temp. 100°F (37.8°C)									
Humid. 80%									
Raising	0	+1	+1	+1	0	0	- .5	-1	-2
Lowering	+3	+4	+4	+3	+3.5	+2.5	+2	+1.5	- .5
Temp. 150°F (65.6°C)									
Humid. 20%									
Raising	-1	-1	-1	-1	-2	-2	-1	-2	-2.5
Lowering	+5	+5	+5	+4	+3.5	+3	+3	+2	- .5
Temp. 150°F (65.6°C)									
Humid. 80%									
Raising	0	-1	0	0	0	-1	-1	-1	-1.5
Lowering	+5	+4	+4	+4	+3.5	+3	+2.5	+1	- .5

Table 10
LIDS Impact Test

Mfr and Model	Maximum Capacity	Impact	Mean Percent Change*
Dillion LI-1	20 ^k	60.5 ^k	.97
Eaton PA-181	10 ^k	30.2 ^k	8.63
Eaton PA-173	30 ^k	90.9 ^k	12.05
Forney 3500-25	25 ^k	75.4 ^k	FAILED
Litton 5084	131 ^k	390.0 ^k	.63
Mark Products System III	25 ^k	76.35 ^k	-.13**
Mark Products System V	25 ^k	75.0 ^k	2.82
Pennant 3L-5	2830 lb (1283.66 kg)	8462 lb (3838.28 kg)	-.45 [†]
Revere R-899	25 ^k	75.74 ^k	-.77
SEQ COWS	20 ^k	62.2 ^k	2.83

$$* \mu = \frac{\sum_{i=1}^n [(Reading \ after \ impact)_i - (Reading \ before \ impact)_i]}{n}$$

where n = the number of samples.

**Readout in volts

[†]Readout in pounds. Cross-sectional area of piston = 7.07 sq in. (45.61 cm²), maximum capacity = 400 psi (2.76 MPa).

Table 11
Boom Angle Indicator Problems

Make and Model	Problem	Solution
Castle 154	Warning light stayed on at all times.	Difficulty was traced to a defective transistor. Replacement resulted in proper operation.
Eaton PA-166	Erratic reading at high temperatures.	Caused by temperature effect on the silicone fluid which filled the angle sensor case. Complete sensor replaced with a new one.
Litton 5084	Erratic reading at low temperatures.	Caused by improper contact within potentiometer of angle sensor. Pendulum was rotated until contact and indication became consistent.
Mark Products System III	Faulty indication meter.	Replacement of meter resulted in proper operation.
Martin-Decker ECA	Indicator did not work.	Too little clearance between angle selector switch mounted on cover and electronic components mounted inside box resulted in the switch tearing off one of the components. The complete indicator unit was replaced.
Revere R-899	High angle warning activated at various angles without regard to setting.	This problem was never solved.
SEQ COWS	Meter indication needle was bent, causing it to stick.	Needle was straightened, resulting in proper operation.

Table 12
Degrees Variation From Actual Angle for Castle Model 154

High Angle Setting- Angle Meter	Boom Angle Setting								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
Degrees Variation									
Temp. -50°F (-45.6°C)									
Humid. —									
Raising	-1	+1	+3	+3	+3	+3	+2	+1	0
Lowering	+4	+6	+7	+7	+6	+5	+4	+4	
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising	-2	0	+2	+2	+2	+2	+2	0	-2
Lowering	+5	+7	+7	+7	+7	+6	+4	+3	
Temp. 40°F (4.4°C)									
Humid. 90%									
Raising	-2	0	+2	+2	+3	+2	+2	0	-1
Lowering	+5	+7	+7	+7	+7	+5	+3	+4	-1
Temp. 70°F (21.1°C)									
Humid. —									
Raising	-1	+1	+2	+2	+3	+3	+2	+1	-2
Lowering	+4	+5	+6	+6	+6	+4	+4	+1	0
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising	-2	0	+2	+2	+2	+1	+1	0	-1
Lowering	+5	+7	+6	+6	+5	+4	+3	+4	
Temp. 100°F (37.8°C)									
Humid. 90%									
Raising	-2	0	+2	+2	+2	+2	+1	0	-1
Lowering	+5	+6	+7	+6	+7	+6	+4	+4	
Temp. 150°F (65.6°C)									
Humid. —									
Raising	-2	0	+2	+2	+3	+2	+1	0	0
Lowering	+5	+6	+7	+7	+5	+6	+6	+3	

Table 13
Degrees Variation From Actual Angle for Eaton Model PA-166

High Angle Setting- Angle Meter	Boom Angle Setting								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
Degrees Variation									
Temp. -50°F (-45.6°C)									
Humid. —									
Raising	-1	-1	-1	-1	-1	0	0	0	-.5
Lowering	-1	0	0	-1	-1	-1	-.5	-1	
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising	-1	-1	-1	-1	-1	-1	-1	-1	-1
Lowering	0	-.5	-.5	0	-.5	-.5	-.5	-.5	
Temp. 40°F (4.4°C)									
Humid. 90°									
Raising	-.5	-1	-1	-1	-1	-1	-1	-1	
Lowering	0	-.5	-.5	-.5	-.5	-.5	0	-1	
Temp. 70°F (21.1°C)									
Humid. —									
Raising	-1	-1	-1	-1	-1	-1	-1	-1	-1
Lowering	+.5	0	0	0	0	0	+.5	0	
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising	-1	-1	-1	-1	-1	-.5	-1	-1	-1
Lowering	0	0	-.5	-.5	0	0	0	0	
Temp. 100°F (37.8°C)									
Humid. 90%									
Raising	0	-.5	-.5	-.5	-.5	-.5	-.5	-.5	-.5
Lowering	-1	0	0	0	0	0	0	0	
Temp. 150°F (65.6°C)									
Humid. —									
Raising	-1	-1	-1	-1	-1	-.5	-1	-1	-1
Lowering	0	-.5	-.5	-.5	-.5	-.5	0	-.5	

Table 14
Degrees Variation From Actual Angle for Eaton Model PA-173

High Angle Setting- Angle Meter	Boom Angle Setting							
	10°	20°	30°	40°	50°	60°	70°	90°
Degrees Variation								
Temp. -50°F (-45.6°C)								
Humid. —								
Raising		-1	-1	-1	-1	0	-1	0
Lowering		0	0	0	0	+1	0	+1
Temp. 40°F (4.4°C)								
Humid. 20%								
Raising		0	-1	-1	0	0	0	0
Lowering		0	0	0	0	+1	+1	+1
Temp. 40°F (4.4°C)								
Humid. 80%								
Raising		-1	-1	-1	0	0	0	0
Lowering		0	0	0	+1	+1	+1	+1
Temp. 70°F (21.1°C)								
Humid. —								
Raising		-1	-1	0	0	0	0	+1
Lowering		-1	-1	-1	+ .5	+1	+1	+1
Temp. 100°F (37.8°C)								
Humid. 20%								
Raising		-1	0	0	0	0	0	+1
Lowering		0	0	0	+1	+1	+1	+1
Temp. 100°F (37.8°C)								
Humid. 80%								
Raising		-1	-1	0	0	0	0	+1
Lowering		0	0	+1	+1	+1	+2	+2
Temp. 150°F (65.6°C)								
Humid. 20%								
Raising		-1	-1	0	0	0	0	+1
Lowering		0	0	0	0	+1	+2	+1
Temp. 150°F (65.6°C)								
Humid. 80%								
Raising		-1	0	0	0	0	+1	+1
Lowering		0	0	0	+1	+1	+1	+2

Table 15
Degrees Variation From Actual Angle for Litton Model 5084

High Angle Setting- Angle Meter	Boom Angle Setting								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
Degrees Variation									
Temp. -50°F (-45.6°C)									
Humid. —									
Raising		0	0	0	0	+1	0	0	
Lowering			0	+1	+1	0	0	0	
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising		0	0	+1	+1	0	+1	+1	
Lowering		0	0	+1	+1	0	0	0	
Temp. 40°F (4.4°C)									
Humid. 80%									
Raising		0	+1	+1	0	0	0	0	
Lowering		0	+1	0	+1	0	0	0	
Temp. 70°F (21.1°C)									
Humid. —									
Raising		0	0	+1	0	0	0	0	
Lowering		0	0	+1	+1	+2	0	0	
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising		0	0	0	0	0	0	0	
Lowering		0	+1	+1	0	0	0	0	
Temp. 100°F (37.8°C)									
Humid. 80%									
Raising		-1	0	0	0	0	0	-1	
Lowering		0	+1	+1	+1	0	-1	0	
Temp. 150°F (65.6°C)									
Humid. 20%									
Raising		+1	+1	+2	0	0	0	0	
Lowering		+2	+2	+2	+2	+2	0	0	
Temp. 150°F (65.6°C)									
Humid. 80%									
Raising		0	0	0	+1	0	0	0	
Lowering		+1	+1	+2	+2	+2	+1	+1	

Table 16
Degrees Variation From Actual Angle for Martin-Decker Model ECA

High Angle Setting- Angle Meter	Boom Angle Setting								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
Degrees Variation									
Temp. -50°F (-45.6°C)									
Humid. —									
Raising	-2	-2	-2	-2	-2	-1	-1	-2	-2
Lowering	-1	-2	-1	-1	-1	-1	-1	-2	-2
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising	-2	-2	-2	-2	-1	-1	-1	-1	-2
Lowering	-2	-2	-2	-1	-1	-1	-1	-1	-2
Temp. 40°F (4.4°C)									
Humid. 90%									
Raising	-2	-2	-2	-1	-1	-1	-1	-2	-2
Lowering	-2	-2	-2	-1	-1	-1	-1	-1	-2
Temp. 70°F (21.1°C)									
Humid. —									
Raising	-1	-2	-2	-1	-1	-1	-1	-1	
Lowering	+1	-1	-1	-1	0	-1	0	-1	
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising	-1	-2	-1	-1	-1	-1	-1	-1	-2
Lowering	-1	-2	-2	-1	-1	-1	-1	-1	-2
Temp. 100°F (37.8°C)									
Humid. 90%									
Raising	-1	-2	-1	-1	-1	-1	-1	-1	-2
Lowering	-1	-2	-2	-1	-1	-1	-1	-1	-2
Temp. 150°F (65.6°C)									
Humid. 50%									
Raising	-1	-1	-1	-1	-1	-1	-1	-1	-1
Lowering	-1	-1	-1	+1	-1	-1	-1	-1	-1

Table 17
Degrees Variation From Actual Angle for Mark Indicator Model XV

High Angle Setting- Angle Meter	Boom Angle Setting								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
Degrees Variation									
Temp. -50°F (-45.6°C)									
Humid. —									
Raising	-1.2	-1.3	-1.1	-.8	-1	-1.6	-1.5	-1.5	-1.5
Lowering	0	+.8	0	0	-.2	-.2	0	+1	+1
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising	-.5	-1	-.5	-.5	-.5	-1	-1	-.5	-.5
Lowering	+.5	+.5	+.5	+.5	+.5	0	0	+.5	+.5
Temp. 40°F (4.4°C)									
Humid. 90%									
Raising	-1	-1	-.5	-.5	-.5	-1	-.5	-.5	-1
Lowering	+.5	+.5	+.5	+.5	+.5	0	0	+.5	0
Temp. 70°F (21.1°C)									
Humid. —									
Raising	-.5	0	-1	0	0	-1	-1	-1	-1
Lowering	0	0	0	0	0	0	0	0	
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising	-.5	-.5	-.5	0	0	0	-.5	0	0
Lowering	0	0	0	+1	+.5	0	0	0	0
Temp. 100°F (37.8°C)									
Humid. 90%									
Raising	-1	-.5	-.5	0	-.5	-.5	-1	-.5	-.5
Lowering	+.5	+.5	+.5	+.5	+.5	0	0	0	+.5

Table 18
Degrees Variation From Actual Angle for Mark Products System III

High Angle Setting- Angle Meter	Boom Angle Setting								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
Degrees Variation									
Temp. -50°F (-45.6°C)									
Humid. —									
Raising	0	0	— .5	-1	-1.5	-2	-2		
Lowering	0	0	-1	-1	-1.5	-2	-2		
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising	— .5	— .5	— .5	— .5	— .5	-1	-1		
Lowering	— .5	0	— .5	— .5	-1	-1	-1		
Temp. 40°F (4.4°C)									
Humid. 90%									
Raising	0	0	— .5	— .5	-1	-1	-1		
Lowering	0	0	— .5	— .5	-1	-1	-1		
Temp. 70°F (21.1°C)									
Humid. —									
Raising	0	0	0	0	— .5	-1	— .5		
Lowering	0	0	0	0	— .5	— .5	— .5		
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising	0	0	— .5	— .5	— .5	— .5	— .5		
Lowering	0	0	— .5	0	— .5	— .5	— .5		
Temp. 100°F (37.8°C)									
Humid. 90%									
Raising	— .5	0	— .5	0	— .5	— .5	— .5		
Lowering	— .5	— .5	— .5	0	— .5	— .5	— .5		
Temp. 150°F (65.6°C)									
Humid. 20%									
Raising	— .5	0	— .5	0	— .5	— .5	0		
Lowering	— .5	0	— .5	0	— .5	0	0		
Temp. 150°F (65.6°C)									
Humid. 90%									
Raising	0	— .5	— .5	0	— .5	— .5	0		
Lowering	0	0	— .5	0	— .5	— .5	0		

Table 19
Degrees Variation From Actual Angle for Mark Products System V

High Angle Setting- Angle Meter	Boom Angle Setting								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
Degrees Variation									
Temp. -50°F (-45.6°C)									
Humid. —									
Raising	-.5	0	0	0	-1	0	-.5	-1	-1
Lowering	0	0	0	0	0	0	0	-.5	
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	
Temp. 40°F (4.4°C)									
Humid. 90%									
Raising	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	
Temp. 100°F (37.8°C)									
Humid. 90%									
Raising	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	
Temp. 150°F (65.6°C)									
Humid. —									
Raising	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	

Table 20
Degrees Variation From Actual Angle for Revere Model R-899

High Angle Setting- Angle Meter	Boom Angle Setting								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
Degrees Variation									
Temp. -50°F (-45.6°C)									
Humid. —									
Raising	— .5	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	0	0
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising	0	0	0	0	0	0	0	0	0
Lowering	0	0	0	0	0	0	0	+ .5	0
Temp. 40°F (4.4°C)									
Humid. 90%									
Raising	0	0	0	0	0	— .5	0	0	0
Lowering	+ .5	0	0	0	0	0	0	0	0
Temp. 70°F (21.1°C)									
Humid. —									
Raising	0	0	0	0	0	0	0	0	— .5
Lowering	0	0	0	0	— .5	0	0	0	— .5
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising	0	0	0	0	0	0	0	0	—
Lowering	0	+ .5	0	0	0	0	0	0	—
Temp. 100°F (37.8°C)									
Humid. 90%									
Raising	0	0	0	0	0	0	0	0	0
Lowering	0	+ .5	0	0	0	0	0	0	0
Temp. 150°F (65.6°C)									
Humid. —									
Raising	0	+ .5	0	0	0	0	0	0	0
Lowering	0	+ .5	+ .5	+ .5	0	0	0	0	0

Table 21
Percent Variation From Actual Radius-to-Load for SEQ Model COWS

Radius Meter	Boom Angle Setting								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
Percent Variation									
Temp. -50°F (-45.6°C)									
Humid. —									
Raising	+ .5	+ .5	+1	+1	+2	+3	- 5.5	+ 1.5	
Lowering	-1	-1	-1.5	0	+ .5	-6	-10	-21	
Temp. 40°F (4.4°C)									
Humid. 20%									
Raising	0	0	+ .5	+1.1	+1.5	+3	+ 3	0	
Lowering	-1	- .5	-2	-1.5	-3	-5	-10	-24	
Temp. 40°F (4.4°C)									
Humid. 90%									
Raising	+ .5	+ .5	+1	+1	+2	+4.5	+ 5	+ 3	
Lowering	-1	-1	-1	-1	-4	+1	-10	-17	
Temp. 70°F (21.1°C)									
Humid. —									
Raising	-1	-3	-2.5	-1.5	-3	-3	- 4.5	- 5.5	
Lowering	-1	-1	-1	-1	0	0	0	- 1	
Temp. 100°F (37.8°C)									
Humid. 20%									
Raising	-1	+2	-1	+1	+1	+4.5	+ 5	0	
Lowering	-2	-3	-2	-1	-1	0	- 3.5	-10	
Temp. 100°F (37.8°C)									
Humid. 80%									
Raising	0	-1	0	+1	+2	+8	+16	+17	
Lowering	-1	-2	-1	-2	-1.5	+1	+ 1	+ 3	
Temp. 150°F (65.6°C)									
Humid. 20%									
Raising	0	-1	- .5	- .5	-1	0	- 3.5	- 7	
Lowering	- .5	-1	-1.5	-1.5	-3	-4	-11	-17	
Temp. 150°F (65.6°C)									
Humid. 80%									
Raising	+ .5	0	+1	+1.5	+1.5	+4	+ 4	+ 1.5	
Lowering	- .5	0	+ .5	+1	+1	+1.5	- 3.5	- 7	

Table 22
Percent Variation From Actual Load for Eaton Model PA-173

		Boom Angle Setting							
		10°	20°	30°	40°	50°	60°	70°	80°
		Percent Maximum Load							
		95	86.7	81.7	78.3	75	80	56.7	
Temp. -50°F (-45.6°C)									
Humid. —									
Alarm On	↑-angle*	-1	0	-2	-1	-2	-3	-1	
Alarm On	↓-angle	-2	-2	-2.5	-2	-2	-1	-5	
Temp. 40°F (4.4°C)									
Humid. 20%									
Alarm On	↑-angle	+ .5	+ .5	- .5	+ .5	- .5	-1	+1.5	
Alarm On	↓-angle	- .5	-1	-1	0	-1	+ .5	-3	
Temp. 40°F (4.4°C)									
Humid. 80%									
Alarm On	↑-angle	+ .5	+1	0	+ .5	0	- .5	+1	
Alarm On	↓-angle	0	0	-1	0	- .5	+1	-2	
Temp. 70°F (21.1°C)									
Humid. —									
Alarm On	↑-angle	+3	+3.5	+2	+3	+2	+1	+7.5	
Alarm On	↓-angle	+1.5	+1.5	+1	+2.5	+2	+3	+5	
Temp. 90°F (32.2°C)									
Humid. 20%									
Alarm On	↑-angle	+2	+2.5	+1.5	+2	+2	+1.5	+4	
Alarm On	↓-angle	+1.5	+2	+1	+2	+1	+3	+ .5	
Temp. 100°F (37.8°C)									
Humid. 80%									
Alarm On	↑-angle	+1.5	+2	+ .5	+2	+1.5	+2	+3	
Alarm On	↓-angle	+1	+1	+1	+2	+1	+2	0	
Temp. 150°F (65.6°C)									
Humid. 20%									
Alarm On	↑-angle	+2	+1.5	+ .5	+2	+1.5	+ .5	+3	
Alarm On	↓-angle	+1	+1	+ .5	+2	+1	+2	- .5	
Temp. 150°F (65.6°C)									
Humid. 80%									
Alarm On	↑-angle	+1.5	+1.5	+ .5	+1.5	-8	+ .5	+2.5	
Alarm On	↓-angle	+ .5	+1	+ .5	+1.5	+1	+2	-1	

*Key:

↑-angle: increasing angle

↓-angle: decreasing angle

Table 23
Percent Variation From Actual Load for Forney System 20

		Boom Angle Setting							
		10°	20°	30°	40°	50°	60°	70°	80
		Percent Maximum Load							
		6.33	7.47	9.67	12.9	19	32.3	71.7	
Temp. -50°F (-45.6°C)									
Humid. —									
Alarm On	↑-angle*	0	+3	0	0	-3	- 3.5	-15	
Alarm On	↓-angle	+4.5	+5	+1	0	-1	- .5	- 9	
Temp. 40°F (4.4°C)									
Humid. 20%									
Alarm On	↑-angle	-1	+ .5	-3	-4	-6	- 6	-11	
Alarm On	↓-angle	- .5	+2	-3	-5	-6	- 4	-11.5	
Temp. 40°F (4.4°C)									
Humid. 80%									
Alarm On	↑-angle	+ .5	+1.5	-2	-5	-6	- 6.5	-11.5	
Alarm On	↓-angle	0	+2	-2	-4.5	-6	- 3.5	-11	
Temp. 70°F (21.1°C)									
Humid. —									
Alarm On	↑-angle	- .5	+1	-3	-4	-6	-10	- 2	
Alarm On	↓-angle	- .5	+1	-3.5	-5	-5	- 8.5	- 2	
Temp. 100°F (37.8°C)									
Humid. 20%									
Alarm On	↑-angle	0	- .5	-3	-3	-5.5	- 6	- 6.5	
Alarm On	↓-angle	- .5	+1	-3	-3	-4.5	- 6.5	- 2	
Temp. 100°F (37.8°C)									
Humid. 90%									
Alarm On	↑-angle	+1	- .5	-2.5	-4	-6	- 7	- 6.5	
Alarm On	↓-angle	+1	+2.5	-2	-3	-6	- 6	- 2	
Temp. 150°F (65.6°C)									
Humid. 20%									
Alarm On	↑-angle	+4	+4	-1	-1.5	-4.5	- 5.5	- 6	
Alarm On	↓-angle	+2	+5	0	-2	-3	- 5.5	- 6	
Temp. 150°F (65.6°C)									
Humid. 80%									
Alarm On	↑-angle	0	+2	-3	-4	-5	- 5.5	- 6.5	
Alarm On	↓-angle	+1	+2.5	-2	-3	-6	- 6	- 6	

*Key:
↑-angle: increasing angle
↓-angle: decreasing angle

Table 24
Percent Variation From Actual Load for Litton Model 5084

	Boom Angle Setting						
	10°	20°	30°	40°	50°	60°	80°
				Percent Maximum Load			
		75.4	76	76.9	78	80	84.6 84.7
Temp. -50°F (-45.6°C)							
Humid. —							
Alarm On ↑-angle*		0	0	0	0	0	-1.5 +10
Alarm On ↓-angle			+ .5	0	+ .5	+1	+2 - 3.5
Temp. 40°F (4.4°C)							
Humid. 20%							
Alarm On ↑-angle		+ .5	+1	0	0	+ .5	+1 - 4
Alarm On ↓-angle		0	+ .5	0	0	+1	+1.5 - 4
Temp. 40°F (4.4°C)							
Humid. 80%							
Alarm On ↑-angle		0	0	- .5	0	+ .5	+ .5 - 4
Alarm On ↓-angle		- .5	0	- .5	- .5	0	0 - 4
Temp. 70°F (21.1°C)							
Humid. —							
Alarm On ↑-angle		+1	+1	0	0	0	0 + 3
Alarm On ↓-angle		0	+ .5	0	0	+1	+1 - 4
Temp. 100°F (37.8°C)							
Humid. 20%							
Alarm On ↑-angle		- .5	-1	-1	-1	-1	0 0
Alarm On ↓-angle		-1	- .5	-1	-1	0	0 0
Temp. 100°F (37.8°C)							
Humid. 80%							
Alarm On ↑-angle		0	0	-1	0	-1	+ .5 + 1
Alarm On ↓-angle		0	0	- .5	0	+ .5	+ .5 - 4
Temp. 150°F (65.6°C)							
Humid. 20%							
Alarm On ↑-angle		+2	+2	+1	+2	+2.5	+2 - 2.5
Alarm On ↓-angle		+1.5	+2	+1	+1.5	+2	+2 - 2.5
Temp. 150°F (65.6°C)							
Humid. 80%							
Alarm On ↑-angle		+1.5	+1.5	+1	+1.5	+2	+2.5 - 2.5
Alarm On ↓-angle		+1.5	+2	+1	+1.5	+2	+2 - 2.5

*Key:
↑-angle: increasing angle
↓-angle: decreasing angle

Table 25
Percent Variation From Actual Load for Mark Products System III

		Boom Angle Setting							
		10°	20°	30°	40°	50°	60°	70°	80°
		Percent Maximum Load							
		10	12.6	16	20.7	26.9	35.5	57	90
Temp. -50°F (-45.6°C)									
Humid. —									
Alarm On	↑-angle*	- 9	+1	+5	0	-3	-2	-10	- .5
Alarm On	↓-angle	-13	0	+2.5	-1	-4	-3.5	-10	
Temp. 40°F (4.4°C)									
Humid. 20%									
Alarm On	↑-angle	- 9	+2	+6	+1	-2	-1	- 7	- .5
Alarm On	↓-angle	- 9	+2	+6	+1	-2	-1	- 7.5	
Temp. 40°F (4.4°C)									
Humid. 90%									
Alarm On	↑-angle	-10	+ .5	+4	0	-2.5	-1	- 7.5	- .5
Alarm On	↓-angle	-11	+1	+5	0	-4	-1	- 7.5	
Temp. 70°F (21.1°C)									
Humid. —									
Alarm On	↑-angle	-13	0	-4	- .5	-3	-1	- 7	-1
Alarm On	↓-angle	-13	0	+4	-1	-3	-1	- 7	
Temp. 100°F (37.8°C)									
Humid. 20%									
Alarm On	↑-angle	-10	+1.5	+5	+1	-1.5	+1	- 5	0
Alarm On	↓-angle	-11	+3	+5.5	+1	-1.5	+1	- 5	
Temp. 100°F (37.8°C)									
Humid. 90%									
Alarm On	↑-angle	-10	+2	+6	+1	-2	+ .5	- 5.5	- .5
Alarm On	↓-angle	-10	+2.5	+6.5	+1	-1.5	+1	- 5	
Temp. 150°F (65.6°C)									
Humid. 20%									
Alarm On	↑-angle	- 8.5	+3.5	+7.5	+2	-1	+2	- 3	0
Alarm On	↓-angle	- 9.5	+3.5	+7	+2	- .5	+2	- 2.5	
Temp. 150°F (65.6°C)									
Humid. 90%									
Alarm On	↑-angle	-10	+3	+6.5	+2	+ .5	+2.5	- 2.5	0
Alarm On	↓-angle	- 9.5	+5	+7	+2	-1	+1.5	- 3.5	

*Key:
↑-angle: increasing angle
↓-angle: decreasing angle

Table 26
Percent Variation From Actual Load for SEQ Model COWS

		Boom Angle Setting							
		10°	20°	30°	40°	50°	60°	70°	80°
		Percent Maximum Load							
		50.9	52	53.9	56.5	60	66.75	79	97.5
Temp. -50°F (-45.6°C)									
Humid. —									
Alarm On	↑-angle*	-2	-1	-2	-1	+2	+2	-3	-1
Alarm On	↓-angle	0	-1	-1	0	+3	+7	+6	
Temp. 40°F (4.4°C)									
Humid. 20%									
Alarm On	↑-angle	-1	-2	-2	-1	+2	+1	-3	-3
Alarm On	↓-angle	-1	-1	-1	0	+4	+7	+5	+5
Temp. 40°F (4.4°C)									
Humid. 90%									
Alarm On	↑-angle	-1	-2	-3	-1	+2	+1	-3	0
Alarm On	↓-angle	-1	-2	-2	0	+6	+6	+5	+4
Temp. 70°F (21.1°C)									
Humid. —									
Alarm On	↑-angle	-1	-1	-1	0	+3	+3	+1	+1
Alarm On	↓-angle	0	+1	0	+1	+6	+4	+3	
Temp. 100°F (37.8°C)									
Humid. 20%									
Alarm On	↑-angle	0	0	0	+1	+4	+1	-1	0
Alarm On	↓-angle	-1	-1	-2	+2	+7	+6	+5	
Temp. 100°F (37.8°C)									
Humid. 80%									
Alarm On	↑-angle	0	-.5	-1	+.5	+3	+1.5	-1	-1
Alarm On	↓-angle	-2	-1	-2	0	+5	+7	+3.5	+.5
Temp. 150°F (65.6°C)									
Humid. 20%									
Alarm On	↑-angle	0	0	-.5	+1	+4	+2.5	+1	+1
Alarm On	↓-angle	+1.5	+1.5	+.5	+2	+5	+3.5	+4.5	
Temp. 150°F (65.6°C)									
Humid. 80%									
Alarm On	↑-angle	-1	-1	-3	-1	+2.5	+1	-1	-1.5
Alarm On	↓-angle	-2	-1.5	-3	-1	+2.5	+2	+1	+1

*Key:

↑-angle: increasing angle

↓-angle: decreasing angle

Table 27
Summary of Field Tests on Load Indicators

	Boom Angle			
	20°	40°	60°	80°
Dillon Model E				
Deviation of load indication	-3.1%	+ 0.42%	-4.0%	-1.6%
Deviation of 90% alarm	-3.0%	- 0.6%	-4.3%	+1.1%
Deviation of 100% alarm	-3.1%	+ 0.42%	-4.0%	-1.6%
Eaton Model PA-181				
Deviation of load indication	+0.84%	+ 0.69%	+0.53%	-0.72%
Deviation of alarm	+3.6%	+ 3.0%	+2.1%	0.0%
Martin-Decker Model SD-12-500				
Deviation of load indication		- 0.2%	+0.3%	
Revere Lodan Model R-901				
Deviation of load indication	+3.1%	+ 2.5%	+1.9%	+1.2%
Deviation of 85% alarm	+8.1%	+ 7.1%	+2.0%	0.0%
Deviation of 100% alarm	+3.1%	+ 2.5%	+1.9%	+1.2%
Forney Sheavemaster SL				
Deviation of load indication	+1.43%	0.0%	-1.07%	0.0%
Deviation of alarm	0.0%	-11.1%	-4.1%	-3.2%

Allowable Limits: -3% to +10% per SAE J-376a

Table 28
Summary of Field Tests on Boom Angle Indicators

	Boom Angle								
	0	10	20	30	40	50	60	70	Max
Dillon Model D									
Deviation of high angle alarm	-4.9°	-1.4°	-0.9°	-0.5°	-0.9°	-0.4°	-0.3°	-0.2°	+0.1°
Deviation of angle indication	-3.7°	-2.1°	-0.8°	-0.7°	-0.6°	0.0°	-0.3°	-0.2°	+0.1°
Deviation of low angle alarm	0.0°	-2.1°	-1.2°	-1.0°	-0.6°	-0.4°	-0.2°	+0.2°	0.0°
Deviation of angle indication	-2.5°	-2.1°	-1.3°	-0.7°	-0.6°	-0.4°	-0.4°	-0.3°	+0.2°
Eaton-Dole Model PA-166									
Deviation of high angle alarm	0.0°	0.0°	0.0°	+2.0°	+0.7°	+0.9°	+1.0°	+1.3°	+1.4°
Deviation of angle indication	0.0°	0.0°	0.0°	+2.0°	+0.7°	+0.9°	+1.0°	+1.3°	+1.4°
Deviation of low angle alarm	0.0°	0.0°	0.0°	+2.0°	+0.7°	+0.9°	+1.0°	+1.3°	+1.4°
Deviation of angle indication	0.0°	0.0°	0.0°	+2.0°	+0.7°	+0.9°	+1.0°	+1.3°	+1.4°
Revere-Lodan Model R-902									
Deviation of high angle indication	0.0°	+0.02°	0.0°	-0.18°	+0.17°	+3.20°	+0.01°	-0.03°	-0.08°
Deviation of low angle indication	0.0°	+0.06°	+0.05°	-0.18°	+0.41°	-0.08°	+0.23°	+0.18°	-0.28°

Allowable Limits: +1.0 degrees to -3.0 degrees below 65° angle
+0.5 degrees to -1.5 degrees at 65° or more per SAE J-375

Table 29
Summary of Field Tests On Moment Computers

Mfr and Model	Type Warning, % Capacity	Actual Load, lb (kg)	÷ .85	Theoretical Angle for Warning	Actual Angle for Warning	Curve Load for Actual Angle, lb (kg)	x .85	Deviation from Curve, %
Mark Products System III	85	12,000 (5 443)	14,100	41°	36.4°	13,400 (6 078)	11,400	+5.3
	85	14,000 (6 350)	16,500	49°	48.7°	16,500 (7 484)	14,000	0.0
	85	24,500 (11 113)	28,800	66°	63.9°	26,500 (12 020)	22,500	+8.9
	100	12,000 (5 443)	—	20°	20°	12,000 (5 443)	—	0.0
	100	12,000 (5 443)	—	40°	40°	14,000 (6 350)	—	0.0
	100	24,500 (11 113)	—	62°	60°	23,000 (10 432)	—	+6.5
	100	52,500 (23 813)	—	80°	79.5°	51,500 (23 360)	—	+1.9
	100	5,735 (2 601)	82 ft (24.99 m)	36°	30.6°	5,250 (2 381)	—	+9.2
	100	5,997 (2 720)	76 ft (23.16 m)	38.4°	37.4°	5,890 (2 672)	—	+1.8
	100	11,713 (5 313)	47 ft (14.33 m)	60.9°	61.8°	12,190 (5 529)	—	-3.9
SEQ COWS			Actual Radius					

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APPENDIX A:

OSHA REGULATIONS

(From *Federal Register*, Vol 37, No. 203,
October 19, 1972)

§ 1918.74 Cranes and derricks other than vessel's gear.

(a) The following requirements shall be met in the use of cranes, whether hoisted aboard a vessel for use thereon or used to service a vessel from the dock, shore, or another vessel, and in the use of any other crane or derrick not a part of a vessel's permanent equipment, but used in longshoring operations:

(1) The crane weight shall be posted on all mobile cranes hoisted aboard vessels for temporary use thereon.

(2) All types of cranes shall be equipped with a durable rating chart visible to the operator, covering the complete range of the manufacturer's (or design) capacity ratings and for which they are certificated, where required. The rating chart shall include all operating radii for all permissible boom lengths and jib lengths as applicable, with and without outriggers which may be fitted, and alternate ratings with optional equipment affecting such ratings. Necessary precautions or warnings shall be included. Operating controls shall be marked, or an explanation posted, at the operator's position to indicate function.

(3) A boom angle or radius indicator shall be fitted where applicable.

(4) All shore-based derricks shall be clearly marked to indicate all applicable capacity ratings, based on manufacturer's (or design) data for which certificated. Such ratings, and any necessary precautions or warnings shall be visible to the operator. Operating controls shall be marked, or an explanation posted at the operator's position to indicate function.

(5) The rated safe working loads of each crane and derrick, for the conditions of use, shall not be exceeded.

(6) No counterweights in excess of manufacturer's (or design) specifications shall be fitted. All equipment shall be used in accordance with manufacturer's (or design) specifications and recommendations.

(7) Pulling of barges or rail cars, and pulling of cargo in such a way as to exert side loading stresses upon crane booms shall not be permitted.

(8) No crane or derrick shall be used in any case where a visible defect affecting safe use exists.

(9) Unless exempted by the provisions of subdivision (viii) of this subparagraph,

every crane used to load or discharge cargo into or out of a vessel shall be fitted with a load indicating device or alternative device in proper working condition which shall meet the following criteria:

(i) The type or model of any load indicating device which is used may be such as to provide (a) a direct indication in the cab of actual weight hoisted or a means of determining this by reference to crane ratings posted and visible to the operator, except that the use of a dynamometer or simple scale alone will not meet this requirement; or (b) an automatic weight-moment device or computer providing indications in the cab according to the radius and load at the moment; or alternatively (c) a device may be used which shall prevent an overloaded condition.

(ii) Accuracy of the load indicating device, weight-moment device, or overload protection device shall be such that any indicated load (or limit), including the sum of actual weight hoisted and additional equipment or "add ons" such as slings, sensors, blocks, etc., is within the range from no less than 95 percent of the actual true total load (5 percent overload) to 110 percent of the actual true total load (10 percent underload). Such accuracy shall be required over the range of the daily operating variables to be expected under the conditions of use.

(iii) The device shall permit the operator to determine before making any lift that the indicating or substitute system is operative. In the alternative, if the device is not so mounted or attached and does not include such means of checking, it shall be certified by the manufacturer to remain operable within the limits stated in subdivision (ii) of this subparagraph for a specific period of time. Checks for accuracy, using known values of load, shall be performed at the time of every certification survey (see § 1918.13) and at such additional times as may be recommended by the manufacturer.

(iv) When the load indicating device or alternative system is so arranged in the supporting system (crane structure) that its failure could cause the load to be dropped, its strength shall not be the limiting factor of the supporting system (crane structure).

(v) Marking shall be conspicuously placed giving (a) units of measure in

pounds or both pounds and kilograms, (b) capacity of the indicating system, (c) accuracy of the indicating system, and (d) operating instructions and precautions. Data providing (a) the means of measurement, (b) capacity of the system, (c) accuracy of the system; and (d) operating instructions and precautions shall similarly be provided in the case of systems utilizing indications other than actual weights. If the system used provides no readout, but is such as to automatically cease crane operation when the rated load limit under any specific condition of use is reached, marking shall be provided giving the make and model of device installed, a description of what it does, how it is operated, and any necessary precautions regarding the system. All weight indications, other types of loading indications, and other data required shall be readily visible to the operator.

(vi) All load indicating devices shall be operative over the full operating radius. Overall accuracy shall be based on actual applied load and not on full scale (full capacity) load. For example, if accuracy of the load indicating device is based on full scale load and the device is arbitrarily set at plus or minus 10 percent, it would accept a reading between 90,000 and 110,000 lbs., at full capacity of a machine with 100,000 lbs., maximum rating, but would also allow a reading between zero and 20,000 lbs., at that outreach (radius) at which the rating would be 10,000 lbs., capacity—an unacceptable figure. If, however, accuracy is based on actual applied load under the same conditions, the acceptable range would remain the same with the 100,000-lb. load but becomes a figure between 9,000 and 11,000 lbs., a much different and acceptable condition, at the 10,000-lb. load.

(vii) When the device uses the radius as a factor in its use or in its operating indications, the indicated radius (which may be in feet and/or meters, or degrees of boom angle, depending on the system used) shall be a figure which is within the range of a figure no greater than 110 percent of the actual radius to a figure which is no less than 97 percent of the actual (true) radius. When radius is presented in degrees, and feet or meters are required for necessary determinations, a conversion chart shall be provided.

(viii) The load indicating device requirements of this subparagraph do not apply to a crane (a) of trolley equipped bridge type while handling containers known to be and identified as empty, or loaded, and in either case in compliance with the provisions of § 1918.85(b) of this part; or while hoisting other lifts by means of a lifting beam supplied by the crane manufacturer for the purpose and in all cases within the crane rating; (b) while handling bulk commodities or cargoes by means of clamshell bucket or magnet; (c) while used to handle or hold hoses in connection with transfer of bulk liquids or other hose handled products; or (d) while the crane is used exclusively to handle cargo or equipment the total actual gross weight of which is known by means of marking of the unit or units hoisted, when such total actual gross weight never exceeds 11,200 lbs., and when 11,200 lbs., is less than the rated capacity of the crane at the maximum outreach that is possible under the conditions of use at the time.

(ix) Effective date of subparagraph (9). The provisions of this subparagraph (9) shall become effective on May 27, 1972, or at the time of the next regular certification survey subsequent to that date.

(10) Accessible areas within the swing radius of the outermost part of the body of a revolving crane shall be temporarily guarded by ropes or other suitable means during cargo operations, so as to prevent an employee being in a position to be caught between the body of the crane and fixed parts of the vessel or of the crane itself.

(11) During the hours of darkness, illumination provided shall be sufficient under the prevailing circumstances so that an operator can see clearly the work area and any signalmen associated with the operation.

(b) The posted safe working loads of mobile crawler or truck cranes under the conditions of use shall not be exceeded.

(c) Accessible areas within the swing radius of the outermost part of the body of a revolving crane shall be temporarily guarded by ropes or other suitable means during cargo operations, so as to prevent an employee being in a position to be caught between the body of the crane and fixed parts of the vessel or of the crane itself.

APPENDIX B:

SAE REGULATIONS*

SAE RECOMMENDED PRACTICE J159 LOAD MOMENT SYSTEM (Tentative as of September 1976)

1. *Scope*—This SAE Recommended Practice applies to mobile cranes when used in lifting crane service which are equipped with load moment devices.

2. *Purpose*—The purpose of this Recommended Practice is to establish the minimum performance requirements of systems used to warn or indicate to the operator or other responsible persons when the load being lifted approaches and meets the rated load value on the applicable load rating chart of the crane.

3. Definitions

3.1 **Load Moment System**—A system consisting of devices which, when applied to a crane, sense crane loading, boom length (telescopic only), boom angle, or functions of these and which automatically signals when the loading conditions approach, reach, and exceed the rated load values.

3.2 **Crane Configuration**—The physical arrangement of the crane as prepared for a particular operation in conformance with the manufacturer's operating instructions and load rating chart.

3.3 **Actual Load**—The weight of the load being hoisted and all additional equipment such as blocks, slings, sensors, etc.

3.4 **Rated Load**—The load value shown on the applicable load rating chart of the crane for the particular crane configuration, boom length, boom angle, or functions of these variables. For radii outside those shown on the load rating chart, the rated load shall be considered as zero.

4. Minimum Performance Requirements

4.1 **Limit and Warning Signals**—An audible and/or visual limit signal shall be activated at 100% of rated load and also whenever the radius shall fall outside the limits of the crane's load rating chart. The limit signal shall continue to function as long as the load is at or in excess of 100% of rated load or as long as the radius is outside the limits of the crane's load rating chart.

An audible and/or visual warning signal, readily distinguishable from the limit signal, shall be activated as the rated load is approached. This warning

signal shall be activated at not more than 90% of the load at which the 100% limit signal is activated.

Audible signals shall be clearly distinguishable to the operator above the noise of the engines and machinery. Visual signals shall be clearly visible to the operator. Their location shall not create an operational hazard.

4.2 **System Capacity**—The Load Moment System capacity shall be either:

- compatible with the maximum capacity of the crane as specified by the crane manufacturer; or,
- compatible with the maximum allowable lift for a specific crane configuration of lesser capacity as specified by the user.

4.3 **Accuracy**—The Load Moment System shall meet the following accuracy requirements.

4.3.1 **LIMIT SIGNAL ACTUATION**—The actual load which activates the limit signal shall be within 90% to 105% of the rated load for the given corresponding radius/angle.

4.3.2 **WARNING SIGNAL ACTUATION**—The actual load which activates the warning signal shall be no greater than 90% of the actual load which activates the limit signal.

4.4 **Additional Functions**—When load, radius, or angle are displayed as additional functions of the Load Moment System, the displayed function shall conform to the following:

4.4.1 **LOAD**—When load indication is displayed as an additional function of the Load Moment System, its accuracy shall be in accordance with SAE J376.

4.4.2 **RADIUS**—When radius indication is displayed as an additional function of the Load Moment System, its accuracy shall be in accordance with SAE J375.

4.4.3 **ANGLE**—When angle indication is displayed as an additional function of the Load Moment System, its accuracy shall be in accordance with SAE J375.

4.5 **Temperature Effect**—Specified accuracy shall be maintained over ambient temperature variations of -30°C to 50°C (-22°F to $+122^{\circ}\text{F}$) without external adjustment.

4.6 **Strength Margin**—When any part of the Load Moment System is employed in the supporting system so that its failure could cause the load to be dropped, its strength margin shall not be less than the minimum strength margin of the other supporting members such as block, hoisting ropes, and rope fittings.

4.7 **Operational Check**—The system shall have a means for the operator or other responsible persons to determine that it is operative prior to use.

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4.8 Testing—The system shall be performance tested by the installer initially and by the user at recommended intervals, or at any time there is an indication of inaccuracy. (See paragraph 4.3, paragraph 4.4, and Section 6.)

5. General Requirements

5.1 Installation and Maintenance—Installation and maintenance of the Load Moment Device and maintenance of the crane should be in accordance with the manufacturer's recommendations to assure system accuracy.

5.2 Labeling—Labels shall be conspicuously placed on a system component(s) or in the operator's cab or both, giving the following information:

5.2.1 Identification of applicable load rating chart and rating conditions.

5.2.2 Units of measure as applicable.

5.2.3 Maximum capacity of the Load Moment System per paragraph 4.2.

5.2.4 Operating range of the Load Moment System for which the accuracy requirements of paragraphs 4.3 and 4.4 are met.

5.2.5 Basic operating instructions and precautions.

5.2.6 Device manufacturer's name, address, model, and serial numbers.

5.2.7 Statement of compliance to SAE Recommended Practice J159 (include appropriate revision).

5.3 Manual—An operation, installation, and service manual(s) shall be provided by the manufacturer and be available to the operator or other responsible persons at all times.

6. Performance Evaluation Tests

6.1 General Testing Requirements:

6.1.1 Specific test instruction shall be provided by the manufacturer.

6.1.2 Test personnel shall be thoroughly familiar with the manufacturer's manuals for the system and shall check system for all functions.

6.1.3 All required equipment shall be on hand, prior to start of test.

6.1.4 System test shall be conducted using an appropriately configured crane and specified load rating chart.

6.1.5 For initial system calibration, tests should be conducted at or near the minimum and maximum of the boom lengths and of the radii/angle with two or more test loads.

6.1.6 For periodic calibration checks, employ one or more test loads of known weight and increase radius until alarms are activated.

6.1.7 **TEST DATA**—Test forms shall include, but not be limited to, the following information:

a. Owner(s).

b. Crane Manufacturer, Model, and Serial Number.

c. Device Manufacturer, Model, and Serial Number.

d. Crane configuration at time of test, method of test load application, location of load sensor, radius/angle sensor, and test readings.

e. A statement that the system met (did not meet) the accuracy requirements of 4.3 and 4.4 or that recalibration was necessary in order to achieve the required accuracy. The system accuracy calculation shall be a part of this report.

6.1.8 All test records shall be signed and dated. A copy of the current test record shall be available at all times.

6.2 Load Test Procedures—Test procedures shall include one of the methods described below or equivalent.

6.2.1 KNOWN WEIGHT:

a. Test load to be applied by suspending known weights (accurate to $\pm 1\%$). If the weights of all additional equipment such as blocks, slings, sensors, etc., are included in the test load, the total load shall be known to an accuracy of $\pm 1\%$. Starting with load at a short radius (load within rating) lift load and increase radius slowly until the Limit Signal is activated. Measure and record radius. Two or more readings should be taken. Similarly, check the Warning Signal.

b. Determine the system accuracy in accordance with paragraph 6.3. System accuracy shall be within the tolerance of paragraph 4.3.

6.2.2 FIXED ANCHOR (Deadman):

a. Test load to be applied by hoisting against a fixed anchor (deadman) equipped with a means for measuring load (accurate to $\pm 1\%$). If the weights of all additional equipment such as blocks, slings, sensors, etc., are included in the test load, the total load shall be known to an accuracy of $\pm 1\%$.

Referring to the crane's load rating chart, position the crane at the desired radius. Adjust the hoisting force, keeping the hoist line vertical within $\frac{1}{2}$ degree. Measure and record radius and value of test load at which the Limit Signal is activated. Two or more readings should be taken. Similarly, check the Warning Signal.

b. Determine the system accuracy in accordance with paragraph 6.3. System accuracy shall be within the tolerance of paragraph 4.3.

6.3 Computations—For each radius measured in the above tests, refer to the applicable load rating chart and determine the rated load. At radii intermediate to those on the load rating chart, rated load shall be determined by linear interpolation unless

otherwise specified by the crane manufacturer.

The system accuracy shall be determined from the following formula:

$$\frac{\text{Test Load}}{\text{Rated Load}} \times 100 = \% \text{ of rated load}$$

SAE RECOMMENDED PRACTICE J248 CRANE OVERLOAD INDICATING SYSTEM TEST PROCEDURE (Approved May 1971)

1. *Scope*—This recommended practice applies to mobile construction type cranes equipped with automatic overload indicating systems complying with SAE J159.

2. *Purpose*—To establish uniform test procedures for overload indicating systems, by the manufacturer and user initially and throughout the system's useful life at recommended intervals.

3. General Requirements

3.1 Become completely familiar with the operating and instruction manuals for the system to be tested and check system for proper function.

3.2 Assemble the required equipment to perform the test, such as level, transit, test weights, tire pressure gage, steel tape, specified boom, etc.

3.3 The crane must be level within $\pm 1.0\%$ grade.

3.4 Test record shall be signed and dated and kept with the crane at all times.

3.5 Test load shall be accurate to $\pm 1.0\%$.

3.6 Tests shall be conducted with properly equipped crane as specified by the manufacturer, including recommended number of parts of load line.

4. Test Procedure

4.1 **Prototype Performance Evaluation Test**—Prototype systems as installed on a crane shall have tests conducted with short, intermediate, and long boom lengths at minimum, medium, and maximum radii in each working area designated on the load rating chart for the given machine.

Two alternate methods for conducting the tests are:

4.1.1 KNOWN WEIGHT

4.1.1.1 Load is applied by suspending known weights.

4.1.1.2 Increase the boom radius to actuate the 100% signal.

4.1.1.3 Test load shall compare with rated load within the tolerances of SAE J159.

4.1.1.4 Boom up and similarly check 90% signal.

4.1.2 FIXED ANCHOR

4.1.2.1 Load is applied by hoisting on a fixed anchor equipped with a force measuring means.

4.1.2.2 Adjust the hoisting force, keeping the hoist line vertical within $\pm \frac{1}{2}$ deg. to actuate the 100% signal.

4.1.2.3 Test load should compare with rated load, within tolerances of SAE J159.

4.1.2.4 Similarly, check 90% signal.

4.2 **Field Testing**—Test two known loads per paragraph 4.1.1 or 4.1.2.

4.2.1 Using boom attached to the crane, test in each working area designated on the load rating chart for the given machine.

4.2.2 Tests shall be conducted at erection with initial boom combination used, and at intervals of not more than six months, or at any time the accuracy is questionable.

5. *Computations*—The percent of rated load accuracy shall be determined from the following:

$$\text{Accuracy} = \frac{\text{Test load}}{\text{Rated load}} \times 100$$

The rated load is determined from the crane's load rating chart for the radius measured in the test.

NOTE: If the crane is equipped with Radius of load measuring device (SAE J375) and load indicating device (SAE J376) which meet with the intent of SAE J159, test in accordance with the individual test procedures.

SAE RECOMMENDED PRACTICE J375a RADIUS-OF-LOAD AND BOOM ANGLE MEASURING SYSTEM (Approved December 1968 and last revised August 1972)

1. *Scope*—This SAE Recommended Practice applies to mobile, construction-type cranes, when used for lifting-crane service.

2. *Purpose*—The purpose of this recommended practice is to establish the performance requirements of systems which measure and display to the operator, or other responsible persons, the radius-of-load or boom angle at which the load is being lifted.

3. Minimum Performance Requirements

3.1 Accuracy Requirements

3.1.1 If the system readout displays radius-of-load, the tolerance range for the indicated radius shall be from 97% of the actual radius to a maximum of 110% of the actual radius. These criteria establish an allowable "under" actual radius indication of 3% of actual radius (overload condition) and an allowable "over" actual radius indication of 10%

of actual radius (underload condition).

3.1.2 If the system readout displays boom angle, the indications shall be as follows:

For boom angles 65 deg or more, the indicated angle shall be from $\frac{1}{2}$ deg greater than the actual angle to $1\frac{1}{2}$ deg less than the actual angle.

For boom angles less than 65 deg, the indicated angle shall be from 1 deg greater than the actual angle to 3 deg less than the actual angle.

3.1.3 Specified accuracy shall be required over the temperature range existing under the condition of use. Means shall be provided to maintain specified accuracy over ambient temperature variations of -20 to $+120$ F (-29 to 49 C).

3.2 The device readout may be in feet, meters, or degrees of boom angle. Degrees of boom angle may be converted to radius using a conversion chart furnished by the crane manufacturer and such converted readings shall fall within the accuracy requirements established by paragraph 3.1.1.

3.3 The device readout shall be so located that the operator can obtain readings within the specified accuracy from his normal operating position and its location shall not create an operational hazard.

NOTE: Installation should be in accordance with manufacturer's recommendation as resolution, parallax, and temperature changes are possible sources of errors.

3.4 Where manually adjustable maximum and minimum working range set points having visual and/or audible indications are included in the system, the operator shall have the respective indications either clearly visible to him and/or be distinguishable from the noise of the engine and machinery.

3.5 The system shall have a means for the operator to determine if the indicating system is operative prior to making any lift.

3.6 **Labeling**—Labels shall be conspicuously placed on the indicating system readout or in the operator's cab or both, giving the following information:

- (a) Operating functions.
- (b) Units of measure.
- (c) Manufacturer's name, address and model number.

3.7 **Testing**—The radius-of-load or boom angle indicator shall be tested by the installer initially and by the user at recommended intervals, or at any time the operator finds an indication of inaccuracy. (See Appendix, paragraph 5 for testing procedure.)

3.8 **Manual**—An operation and instruction manual shall be provided by the manufacturer and be available to the operator at all times.

NOTE: When this system is used in combination with load indicating devices (SAE J376) and the two together are to be considered in lieu of an overload indicated system (SAE J159), set points are required. See paragraph 3.4.

APPENDIX

4. Definitions

4.1 **Radius-of-Load**—The horizontal distance from a vertical projection of the axis of rotation to the supporting surface, before loading, to the center of vertical hoist line or tackle with load applied.

4.2 **Boom Angle**—The angle between the longitudinal axis of the boom base section and the horizontal plane.

5. **Testing**—Test instructions shall be supplied by the manufacturer.

5.1 General Requirements

5.1.1 Become completely familiar with the operating and instruction manuals for the system to be tested and check system for proper function.

5.1.2 Assemble the required equipment to perform the test, such as level (minimum accuracy of $\pm\frac{1}{4}$ deg), transit, steel tape, etc.

5.1.3 Tests should be conducted with crane equipped as specified by the manufacturer.

5.1.4 Testing of the system should include positioning the boom so that the radius-of-load or boom angle indicator reading is within the lower working range of the load rating chart (or as restricted by the job site), the mid-working range, and near maximum recommended working angle.

The test should be repeated in reverse order to recheck each of the aforementioned ranges.

Accuracy shall be within the tolerance of paragraph 3.1.

5.1.5 All test records should be signed and dated and a copy of the current test record kept with the crane at all times.

5.2 General Procedure

5.2.1 Level the crane within the equivalent of a 1% grade or $\pm\frac{1}{2}$ deg in an area that is clear of obstructions so that the boom may be moved from maximum radius (minimum boom angle) to the minimum radius (maximum boom angle).

5.2.2 Where specific manufacturer's test instructions are not available, one of the following methods is suggested:

- (a) The radius-of-load at each test position should be measured by steel tape or equivalent calibrated means and the measurement compared to the radius-of-load or angle indicator reading (convert radius-of-load to boom angle where required or use manufacturer's conversion table when compensation for loaded boom deflection has been provided).

(b) The boom angle at each test position should be measured by an adjustable level or protractor (calibrated in degrees with minimum accuracy of $\frac{1}{4}$ deg) or equivalent calibrated means and the measurement compared to the angle indicator reading. The adjustable level or protractor should be positioned on a smooth surface of the base boom section parallel with the longitudinal centerline.

**SAE RECOMMENDED PRACTICE J376a
LOAD INDICATING DEVICES IN LIFTING
CRANE SERVICES (Approved December 1968
and last revised October 1974)**

1. *Scope*—This SAE Recommended Practice applies to mobile cranes when used for lifting-crane service, and which are equipped with load indicating devices.

2. *Purpose*—The purpose of this recommended practice is to establish the minimum performance requirements of devices used to measure and display to the operator or other responsible persons the weight of the load being lifted. It is not the intent of this recommended practice to define the requirements and use of weight measuring devices used in commerce or other industries.

3. *Definitions*

3.1 **Load Indicating System**—A load indicating device applied to a crane. It includes all mounting and crane components that affect operational performance.

3.2 **Crane Configuration**—The physical arrangement of the crane as prepared for a particular operation in conformance with the manufacturer's operating instructions and load rating chart.

3.3 **Actual Load**—The weight of the load being hoisted and all additional equipment such as blocks, slings, sensors, etc.

4. *Minimum Performance Requirements*

4.1 **Load Indicating System Capacity**—The Load Indicating System capacity shall be either:

(a) compatible with the maximum capacity of the crane as specified by the crane manufacturer,

or

(b) compatible with the maximum allowable lift for a specific crane configuration of lesser capacities specified by the user.

4.2 **Accuracy**—The accuracy of the Load Indicating System shall be such that the indicated load is within 97% to 110% of the actual load. When operating at rated load, the 97% value establishes a limit of 3% above the rated load. Refer to the device manufacturer's instructions for proper operating

procedure. It is recognized that not all systems may be accurate over the entire range of the crane's load ratings, and where the system cannot meet the accuracy requirement, visual or audible means, or conspicuous labeling, shall be provided for, indicating that range where the system cannot meet the accuracy requirement. Supplementary load indicating devices may be employed to extend the operating range.

4.3 **Temperature Effect**—Specified accuracy shall be maintained over ambient temperature variations of -20°F to $+120^{\circ}\text{F}$ (-29°C to $+49^{\circ}\text{C}$) without external adjustment.

4.4 **Readout**

4.4.1 The device readout should be in units of measure which are compatible with the appropriate load rating chart for the crane. Minimum resolution shall permit the clear indication of values within the accuracy requirements of the system, under all conditions of operation.

4.4.2 The device readout shall be located so that the operator or other responsible person can obtain readings from his normal operating position and its location shall not create an operational hazard.

4.5 **Set Points**—Load indicating systems may be equipped with manually adjustable working range set points having a visual or audible warning signal. When so equipped, visual signals shall be clearly visible and audible signals must be clearly distinguishable above the noise of engines and machinery.

4.6 **Operation Check**—The system shall have a means for the operator or other responsible person to determine that it is operative prior to use.

4.7 **Testing**—The load indicating system shall be performance tested by the installer initially and by the user at recommended intervals, or at any time there is an indication of inaccuracy. (See accuracy requirements in paragraph 4.2 and testing procedure in Section 6.)

4.8 **Strength Margin**—When any part of the load indicating system is employed in the supporting system so that its failure could cause the load to be dropped, its strength margin shall not be less than the minimum strength margin of other supporting members, such as block, hoisting ropes and rope fittings.

5. *General Requirements*

5.1 **Installation and Maintenance**—Installation and maintenance of the load indicating device and maintenance of the crane should be in accordance with the manufacturer's recommendations to assure system accuracy.

5.2 **Labeling**—Labels shall be conspicuously placed on the device readout or in the operator's cab

or both, giving the following information:

5.2.1 Units of measure.

5.2.2 Maximum capacity of the load indicating system.

5.2.3 Operating range of the Load Indicating System for which the accuracy requirement of paragraph 4.2 is met.

5.2.4 Basic operating instructions and precautions. Included shall be a precaution that calibration adjustments shall be made only using procedures approved by the manufacturer.

5.2.5 Manufacturer's name, address and device model number.

5.2.6 Statement of compliance with SAE Recommended Practice J-376a.

5.3 Manual—An operation, installation and service manual(s) shall be provided by the manufacturer and shall be available to the operator or other responsible persons at all times.

6. Performance Evaluation Tests

6.1 General Requirements

6.1.1 Specific test instructions for the device shall be provided by the manufacturer.

6.1.2 Test personnel shall be thoroughly familiar with manufacturers' manuals for the system and shall check system for all functions.

6.1.3 All required equipment shall be on hand prior to start of test.

6.1.4 System test shall be conducted using an appropriately configured crane and load rating chart.

6.1.5 For system calibration, two or more test loads shall be employed to establish compliance with paragraph 4.2. Test loads shall be as near as is practical to the upper and lower limits of the operating range.

6.1.6 For periodic calibration checks, one or more test loads shall be employed.

6.2 Test procedures shall include one of the two methods described below or equivalent:

6.2.1 KNOWN WEIGHT

(a) Test load to be applied by suspending known

weights (accurate to $\pm 1\%$). If the weights of all additional equipment such as blocks, slings, sensors, etc., are included in the test load, they shall be known to an accuracy of $\pm 1\%$. Compare the test load to the indicated load.

(b) System accuracy shall be within the tolerances of paragraph 4.2.

6.2.2 FIXED ANCHOR (Deadman)

(a) Test load to be applied by hoisting against a fixed anchor (deadman) equipped with a means for measuring load (accurate to $\pm 1\%$). If the weights of all additional equipment such as blocks, slings, sensors, etc., are included in the test load, they shall be known to an accuracy of $\pm 1\%$. Compare the test load to the indicated load.

(b) System accuracy shall be within the tolerances of paragraph 4.2.

6.3 Test Data

6.3.1 Test forms shall include, but not be limited to, the following information.

(a) Owner(s)

(b) Crane Manufacturer, Model, Serial Number

(c) Device Manufacturer, Model, Serial Number

(d) Crane configuration at time of test, method of test load application, load application, location of load sensor, test load data, and load determining curve, if used.

(e) A statement that the system met (did not meet) the accuracy requirement of paragraph 4.2 or that recalibration was necessary in order to achieve accuracy. The system accuracy calculation shall be a part of this report.

6.3.2 All test records shall be signed and dated. A copy of the current test record shall be available at all times.

6.4 Computations—The system accuracy shall be determined from the following formula:

$$\text{Percentage} = \frac{\text{Indicated Load}}{\text{Actual Load}} \times 100$$

Percentage tolerance limits: 97% to 110%

APPENDIX C:

LABORATORY TEST PROCEDURES

1 SPECIFICATION

Purpose

To establish a uniform testing procedure for laboratory testing of crane load-moment and load-and boom-angle-indicating devices. The testing specified herein is intended:

1. To provide system accuracy data on a 100 percent basis from laboratory testing of each system.
2. To provide performance characteristics by type or model as evidence of durability by testing under varied environmental conditions.

Scope

To provide a standard against which the operation of each system can be compared, and to define test conditions so that all systems will be tested identically.

Referenced Documents

The latest issues of the following Military Specifications shall form a part of this procedure except as specified herein:

1. MIL-STD-810 Environmental Test Methods
 - a. High Temperature—Method 501 Procedure II
 - b. Low Temperature—Method 502 Procedure I
2. MIL-C-45662 Calibration of Standards

Standards for Comparison

Load Cell Standard

The standards with which the commercial cells will be compared are the MTS load cells presently installed in the 1,000-kip (4 448 222 N) and 50-kip (222 411 N) MTS test machines. Calibration data for these cells already exist. The cells are periodically calibrated against a standard load cell that is traceable to NBS.

Boom Angle Standard

The commercial boom angle sensors will be com-

pared with the graduated scale of a Palmgren No. 1062G22 rotary table. The table is accurate to 1/20 of a degree.

Testing Conditions

Temperature

1. The range of temperature for testing standards shall be from -50° to $+150^{\circ}\text{F}$ (-45.6° to 65.6°C).
2. Systems shall be tested at -50° and $+150^{\circ}\text{F}$ (-45.6° and 65.6°C), and at increments of 20°F (11.1°C) between these limits.

Humidity

1. The range of humidity for testing shall be from low to high over the temperature range of 40° to 150°F (4.4° to 65.6°C).
2. Systems shall be tested at relative humidities of 20 and 90 percent at high and low test temperatures.

Load Cell Shock Survivability

The final test will subject the load cell to a suddenly applied force equal to three times the maximum load rating of the cell. This will simulate a dropping load which is stopped by sudden application of the clutch.

2 CALIBRATION PROCEDURE

Calibration of Standard Load Cell

This cell is already calibrated. As it will never be inside the environmental chamber, no further calibration is necessary.

Calibration of Tested Equipment

1. Test each manufacturer's load cell and boom angle together.
2. Calibrate each indicating device system while it is completely assembled and functioning as if the equipment were field-installed on a crane.
3. Mount the boom angle sensor on the rotary table. Rotate the table until the boom angle sensor's output voltage corresponds to the manufacturer's 0 degrees output voltage; use that table position as 0

degrees. Turn table to 90 degrees and adjust the gain to obtain a full-scale reading.

4. Mount the load cell in the test frame, using any shackles, clevises, or other devices needed to center the load cell properly and insure that the load is applied as specified for the particular cell being tested.

Calibration Runs on Boom Angle Sensors

Calibration Output Voltage

1. Obtain the output voltage from the boom angle meter input circuit or after preamplifiers. If the indicator system displays a radius output, obtain an output voltage before the sensor voltage is manipulated to compute the radius.

2. Connect the output voltage to a digital voltmeter capable of reading the voltage to four digits.

Room Temperature Runs

1. Allow the system to sit in the environmental chamber at room temperature while the system is on. Allow the system to warm up the minimum amount of time specified by the manufacturer before testing.

2. Record the calibration voltages at each 10-degree increment, starting at 0 degrees, increasing to 90 degrees, then decreasing to 0 degrees. This cycle will be repeated 10 times to give a total of 180 readings.

Low and High Temperature Runs

Set the environmental chamber for 70°F (21.1°C). After the temperature of the indicator system reaches the chamber temperature (usually requires 1 hour), run the test series outlined in paragraph 2 above. From 70°F (21.1°C), decrease the temperature in 20°F (11.1°C) increments, running a test series at each step. After testing the system at -50°F (-45.6°C), raise the temperature to 90°F (32.2°C) and run a test series. Continue to increase the temperature at 20°F (11.1°C) intervals to 150°F (65.6°C), running a calibration series at each step.

Calibration Runs on the Load Cells

Calibration Output Voltage

1. Obtain the output voltage from the load meter

input voltage, or from locations specified by the manufacturer.

2. Connect the output voltage either directly or by a selector switch to a digital voltmeter capable of displaying readings with four digits.

Room Temperature Runs

1. Allow the system to remain in the environmental chamber at room temperature while the system is on. Warm the system up at least the minimum time specified by the manufacturer for that system.

2. Divide the maximum load rating of the load cell into 10 equal parts. Starting at 10 percent of maximum load, record the voltage output reading at each 10 percent step up to 100 percent; then decrease to 10 percent by 10 percent steps, recording the 10 percent value giving 19 readings per cycle. Repeat the cycle nine times.

Low and High Temperature Runs

Procedure progresses as outlined for high and low temperature calibration runs on boom angle sensors.

3 TEST PROCEDURE

Load Indicator Systems

Systems With Maximum Load Settings

1. With the indicator system at room temperature, set the alarm load at 10 percent of the maximum load of the system. Slowly load the cell, recording the actual load at which the alarms and (if equipped) prealarms are activated. Also record the load meter reading when the cell is loaded at the 10 percent maximum load value. Raise the load to 100 percent maximum load and observe whether the alarms remain activated during the overload.

2. Reverse the above process, recording when the alarm and (if equipped) prealarms deactivate. Also record the meter readout when the cell is loaded at the 10 percent load level. Reduce the load below the deactivating load level and observe if alarms remain off.

3. Repeat the procedures in steps 1 and 2, increasing the alarm setting to 100 percent by 10 per-

cent increments; then decreasing to 10 percent of the maximum load.

Systems Without Maximum Load Settings

1. Apply load to the load cell in increments of 10 percent of the maximum until the maximum is reached. At each step compare the load indicator reading with the force determined by the load cell of the testing machine. Use the testing machine to indicate the steps and to show how the indicator varies from the true value.

2. Reverse the above procedure, taking readings as the load is removed in 10 percent increments.

Boom Angle Systems

Systems With High- and Low-Angle Alarms

1. With the indicator system at room temperature and the rotary table at 0 degrees, set the high alarm to 90 degrees and the low alarm to 10 degrees. Slowly raise the rotary table angle, recording the angle at which the low-angle alarm deactivates and the angle meter readout when the rotary table is at 10 degrees. Increase the rotary table angle to 90 degrees observing whether the low-angle alarm remains off. Decrease the rotary table angle, recording the angle at which the alarm activates and the value that the angle meter readout is displaying at 10 degrees.

2. Repeat the above procedure at each 10-degree setting until a high angle of 80 degrees is reached.

3. With the rotary table at 90 degrees, set the high alarm to 80 degrees and the low alarm to 0 degrees. Slowly lower the rotary table angle, recording the angle at which the high-angle alarm deactivates. Continue lowering the rotary table angle observing whether the high-angle alarm remains off. Increase the rotary table angle, recording the table angle at which the high alarm activates.

4. Repeat the above procedure at each 10-degree setting until a low angle of 10 degrees is reached.

Systems Without High- and Low-Angle Alarms

1. Starting with the rotary table at 0 degrees, rotate the table in increments of 10 degrees until 90 degrees is reached. At each step compare the angle indicator reading with the setting of the rotary table. Use the rotary table indicator to indicate the steps

and to show how the angle displayed on the test specimen indicator varies from the true value.

2. Reverse the above procedure, taking readings as the angle is decreased in 10-degree increments.

Load Moment Systems

1. Operate the indicator system at room temperature and allow the system to warm up for the length of time recommended by the manufacturer.

2. From the crane load-angle curves on which the load moment system was designed, compute the maximum allowable load at each 10-degree step of the allowable boom angle range. (Note: The boom angle range will vary from manufacturer to manufacturer.)

3. Load the cell with the overturning load corresponding to the lowest boom angle (10 or 20 degrees in most cases), with the rotary table angle at 0 degrees. Slowly increase the table angle, recording the angles at which the prealarm (if equipped) and alarms deactivate. Also record the capacity meter and angle meter display values when the table angle corresponds to the overturning angle. (Note: The capacity meter will either be in percent overturning load, percent overturning moment, or allowable load for the corresponding angle.) Continue increasing the table angle observing whether the alarms remain off. Slowly decrease the table angle, recording the table angle at which the alarms activate and the angle meter readout when the table angle corresponds to the overturning angle.

4. Repeat the procedure using overturning load values at 10-degree increments up to the manufacturer's maximum angle (usually 80 degrees), then in decreasing steps to the manufacturer's minimum angle.

5. Set the rotary table angle to the minimum value (10 or 20 degrees). Starting with zero load applied to the load cell, slowly increase the applied load, recording the loads at which the overload alarms activate. Also record the load meter readout (if equipped) at the applied overturning load level. Continue to increase the applied load, observing whether the alarms remain on. Decrease the applied load, recording the applied load values at which the alarms deactivate and the load meter (if equipped) readout at the overturning load corresponding to the set angle. Continue decreasing the load, observing

whether the alarms remain off.

6. Repeat the procedure setting the angle at 10-degree increments up to the manufacturer's maximum angle (usually 80 degrees), then decrease by steps until the manufacturer's minimum angle is reached.

7. Test moment computer systems equipped with high- and low-angle alarm systems according to procedures given for boom angle systems with high- and low-angle alarms in addition to the regular moment computer test.

Low Temperature Test

1. Place load and angle sensor within the environmental chamber along with temperature-compensating devices or preamplifier if equipped. Decrease the chamber temperature to -50°F (-45.6°C) and allow the components to stabilize.

2. Repeat the series of tests outlined in the first three sections of this chapter.

High Temperature and Humidity Test

1. With the components still in the environmental chamber, raise the temperature to 150°F (65.6°C) with a 90 percent relative humidity and allow the components' temperature to stabilize.

2. Repeat the series of tests outlined in the first three sections of this chapter.

3. Repeat the test procedure at 150°F (65.6°C) with the relative humidity at 20 percent. Then run the same series at 100° and 40°F (37.8° and 4.4°C) with relative humidities of 20 and 90 percent.

Load Cell Shock Survivability Test

1. Program the test machine for a maximum load of three times the rated maximum working load of the cell. The program will apply the load for 500 msec, then release (use a square wave input function).

2. Check load cell against original calibration.

APPENDIX D:

CERL CLOSED-LOOP MATERIALS TESTING SYSTEM

The CERL closed-loop materials testing system consists of two load frames, two control consoles, and one hydraulic power supply. Closed-loop applies to systems in which a control signal is generated by comparing desired (programmed) and actual (as sensed by a transducer) conditions of the controlled variable. A control element, such as an electro-hydraulic servovalve, instantly responds to the control signal and maintains the parameter being controlled at the command or programmed level.

The system operates under the "closed-loop" control principle which permits controlled operation of a number of modes. That is, the system can be operated in load control or stroke control, or it can be controlled from a transducer attached directly to the test specimen. Closed-loop control permits a wide range of programming as well as control.

One of the two load frames has a maximum static force capability of ± 50 kips (222 411 N) and a dynamic force capability of ± 25 kips (111 206 N). The other has a maximum static force capability of $\pm 1,000$ kips (4 448 222 N) and a maximum dynamic force capability of ± 500 kips (2 224 111 N). Four columns in each frame provide an extremely rigid reaction for the specimen and good access to the specimen for an environmental chamber. The forcing actuator and servovalve are mounted on the lower part of the frame with the actuator rod protruding through the base to the lower specimen grip. Load, stroke, and strain transducers provide feedback signals for control and readout. The 50-kip (222 411 N) frame has a 10-in. (25.4 cm) stroke and the 1000-kip (4 448 222 N) frame has a 20-in. (30.8 cm) stroke.

The system can be programmed by any electronic device that produces a varying DC voltage. Included with the system are three types of programmers. The first is an arbitrary function generator that permits the operator to draw an arbitrary program as a function of time. The second is a cyclic function generator capable of producing sine, triangle, square, and ramp functions over a wide frequency range. The

third is a digital ramp generator capable of producing strain or load command functions for determining the stress-strain characteristics of a material or component. Other types of programmers which could be used include random noise generators, analog computers, and various types of digital programming devices.

All conditioned output signals are "high level," ± 10 V, and low noise, and are readily adaptable to almost any kind of recording device, including computers. Three types of recorder are included with the system. The first is an X-Y₁-Y₂ plotter. The second is a dual-beam storage oscilloscope for displaying load, stroke, or strain versus time or each other. The third is a dual digital display which simultaneously tracks and displays the applied load and any other parameter in the test system. During cyclic testing, the upper and lower peak values of the load can be displayed simultaneously.

The system is modular in construction, thus permitting easy expansion or modification to meet desired testing requirements.

Accuracy of the system is principally determined by the combined accuracy of the transducer and the control loop. The overall accuracy is substantially better than .25 percent of the transducer range.

Table D1 shows the expected performances when a sinusoidal loading is applied. The frames are also capable of applying static loads to the specimens as commanded from the control console.

Table D1
Expected Performance Under Sinusoidal Loading

Load Frame	Load, kips (N)	Displacement, in. (mm)	Frequency, Hz
1000-kip (4 448 222 N)	± 500 (2 224 111)	± 0.01 (0.21)	3
	± 500 (2 224 111)	± 3.00 (61.62)	0.02
	± 100 (444 822)	± 0.01 (0.21)	15
	± 100 (444 822)	± 3.00 (61.62)	0.1
50-kip (222 411 N)	± 25 (111 206)	± 0.01 (0.21)	30
	± 25 (111 206)	± 3.00 (61.62)	0.3

APPENDIX E:

REGRESSION ANALYSIS

1 INTRODUCTION

Background

Load-indicating device systems (LIDS) and boom-angle-indicating device systems (AIDS) are designed to provide a linear output voltage corresponding to an independent input variable such as a compressive load or an angle from a set plane. The linear response is programmed to drive a digital display or meter indicating the magnitude or multiple of the input variable. Discrepancies from the input and output values arise due to drift, hysteresis, and non-linearity in the response. Most AIDS and LIDS manufacturers include some means of adjusting for drift in a system, often a zero and gain control which allows the system to be calibrated. With calibration controls, a system's accuracy depends on the effect of hysteresis and nonlinearity within its components.

Purpose

The objective of this analysis is to determine the accuracy of several types and makes of load- and angle-indicating devices used for mobile cranes. Properties of these devices to be investigated are linearity of response, presence of hysteresis, and variation of response with temperature.

Scope

Calibration runs were performed on each LID and AID system, including systems with radius readout instead of angle readout. Appendix C outlines the calibration procedure. These tests provided response data. Tables E1 and E2 are examples of laboratory data for the boom angle and load indicators. A regression analysis with an equation best fitting the response data was developed to compensate for the expected drift effects. The analysis further provides a means of determining the variation of response and hysteresis of a system over a range of temperatures.

Table E1
Calibration of Angle Sensor

Manufacturer: Mark Indicator
R-408

Temperature 50°F (10°C) Supply 12V

			Boom Angle									
			0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
1	Raise	4.229	4.419	4.626	4.839	5.041	5.245	5.444	5.647	5.855	6.069	
1	Lower	4.228	4.434	4.636	4.838	5.044	5.250	5.460	5.658	5.862	—	
2	Raise	—	4.422	4.630	4.838	5.040	5.247	5.450	5.652	5.860	6.064	
2	Lower	4.234	4.430	4.635	4.845	5.047	5.252	5.465	5.653	5.865	—	
3	Raise	—	4.423	4.630	4.847	5.045	5.248	5.446	5.650	5.857	6.063	
3	Lower	4.228	4.430	4.635	4.844	5.053	5.251	5.454	5.654	5.862	—	
4	Raise	—	4.426	4.635	4.838	5.040	5.248	5.447	5.651	5.855	6.064	
4	Lower	4.230	4.429	4.639	4.843	5.048	5.251	5.459	5.654	5.859	—	
5	Raise	—	4.423	4.630	4.840	5.045	5.249	5.450	5.648	5.858	6.064	
5	Lower	4.227	4.432	4.640	4.840	5.047	5.250	5.457	5.656	5.862	—	
6	Raise	—	4.424	4.630	4.839	5.041	5.252	5.450	5.657	5.854	6.064	
6	Lower	4.226	4.430	4.634	4.842	5.044	5.250	5.456	5.657	5.861	—	
7	Raise	—	4.424	4.630	4.837	5.045	5.248	5.451	5.647	5.860	6.064	
7	Lower	4.225	4.430	4.636	4.837	5.042	5.253	5.457	5.655	5.861	—	
8	Raise	—	4.422	4.630	4.832	5.040	5.248	5.452	5.648	5.853	6.069	
8	Lower	4.229	4.435	4.634	4.837	5.041	5.251	5.457	5.655	5.860	—	
9	Raise	—	4.423	4.628	4.838	5.040	5.251	5.446	5.646	5.856	6.069	
9	Lower	4.230	4.425	4.633	4.843	5.046	5.250	5.450	5.654	5.859	—	
10	Raise	—	4.427	4.629	4.839	5.040	5.251	5.450	5.655	5.853	6.062	
10	Lower	4.234	4.423	4.615	4.822	5.026	5.251	5.457	5.654	5.861	—	

Table E2
Calibration of Load Cell

Manufacturer: Revere Lodan										
Temperature 70° (21.1°C) Supply 24 V Max. Force 25,000 lb										
	10% 2500	20% 5000	30% 7500	40% 10,000	50% 12,500	60% 15,000	70% 17,500	80% 20,000	90% 22,500	100% 25,000
1 Raise 17.5	43.2	68.7	94.2	119.9	145.8	171.6	196.9	222.4	247.8	273.3
1 Lower 17.4	43.0	68.6	94.1	119.8	145.7	171.0	196.7	222.1	247.7	—
2 Raise	43.0	68.5	94.2	119.8	145.7	171.3	197.0	222.4	247.8	273.3
2 Lower 17.5	43.1	68.7	94.2	119.9	145.6	171.5	196.6	221.9	247.6	—
3 Raise	43.3	68.8	94.8	119.8	145.8	171.3	196.9	222.2	247.6	273.1
3 Lower 17.5	43.2	68.7	94.3	120.1	145.6	171.3	196.8	222.5	247.8	—
4 Raise	43.1	68.7	94.3	119.8	146.0	171.7	197.1	222.2	247.8	273.0
4 Lower 17.4	43.0	68.5	94.1	119.8	145.6	171.3	196.7	222.0	247.8	—
5 Raise	43.1	68.6	94.1	119.8	145.7	171.5	196.6	222.2	247.8	273.0
5 Lower 17.5	43.2	68.5	94.1	120.1	145.5	171.1	196.6	222.3	247.7	—
6 Raise	43.1	68.7	94.4	120.0	146.0	171.2	196.7	222.2	247.7	272.9
6 Lower 17.5	43.1	68.6	94.2	120.1	145.5	171.4	196.6	222.2	247.7	—
7 Raise	43.1	68.7	94.3	120.1	145.7	171.4	197.0	222.2	247.5	273.4
7 Lower 17.6	43.1	68.6	94.2	120.0	145.5	171.2	196.6	222.1	247.7	—
8 Raise	43.1	68.7	94.3	120.0	146.0	171.2	197.0	222.2	247.8	273.3
8 Lower 17.6	43.3	68.5	94.3	120.1	145.7	171.3	196.6	222.8	247.8	—
9 Raise	43.1	68.8	94.4	120.2	146.3	171.9	197.4	222.8	248.2	273.9
9 Lower 17.9	43.4	69.0	94.5	120.6	146.1	171.5	197.2	222.6	248.0	—
10 Raise	43.5	69.2	94.8	120.1	146.1	171.8	197.4	222.8	248.3	273.7
10 Lower 17.9	43.4	68.9	94.3	120.2	146.1	171.6	197.0	222.7	248.0	—

2 LINEAR REGRESSION ANALYSIS

Theory

Given a linear response system with a gain control (β) and a zero control (a), the response system can be mathematically described by:

$$y = a + \beta x \quad (\text{Eq E1})$$

where y = the output voltage

x = the input angle or load (independent variable).

Given an amount of output voltage data (y_i) corresponding to various input angles or loads (x_i), y and x can be compared. One method of comparison is a linear regression analysis.

A linear regression analysis is valid for use on linear response data provided that two basic assumptions are true:¹³

¹³William B. W. Ang and Wilson Tang, *Stochastic Concepts in Civil Engineering* (University of Illinois, 1972), p 249.

1. The voltage output data (y_i) is normally distributed around the calculated voltage (y) at each angle or load (x).

2. The variance of y_i about y is constant throughout the angle or load range.

The first assumption can be partially verified by histograms of the data; histograms are graphs of the voltage differences ($y - y_i$) and the frequency of the voltages occurring in a set interval. Figures E1 and E2 are histograms of the Mark Products System III data. The second assumption was investigated after the analysis was performed on the data. The values listed along the lines indexed "STD.CV" in the computer printouts labeled "***** Coefficients of Variation *****" indicate the extent to which the variation is independent of the boom angle or the load.

Determining the linear equation can be accomplished by the method of least squares. Ang and Tang¹⁴ derive the following equations for a and β from the least squares method:

¹⁴Ang and Tang, p 250, 251.

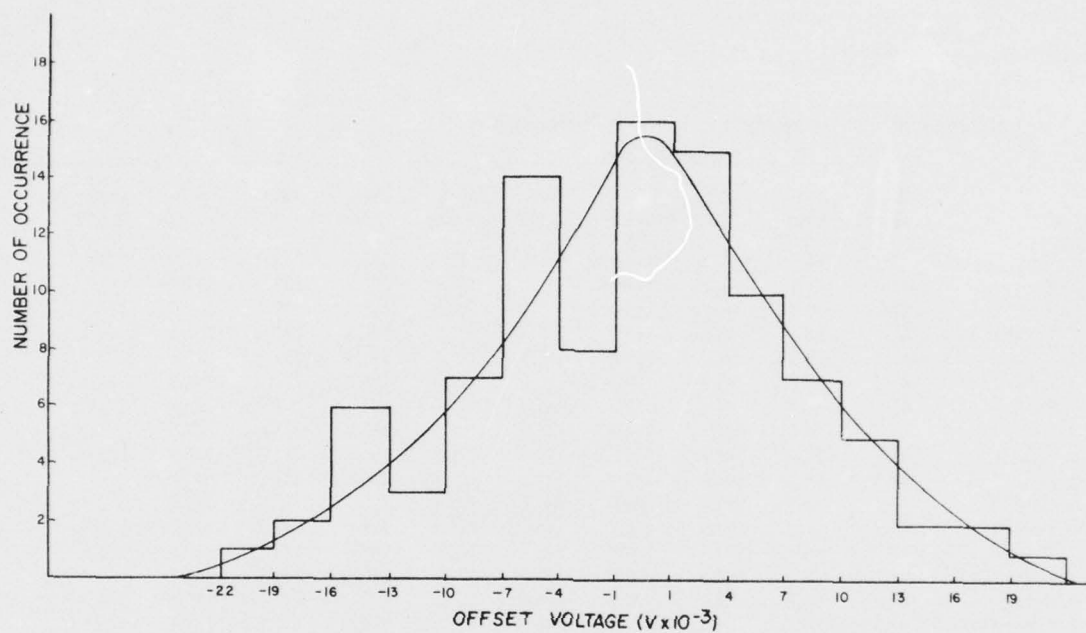


Figure E1. Histogram of Mark Products System III data (30°F or -1.1°C).

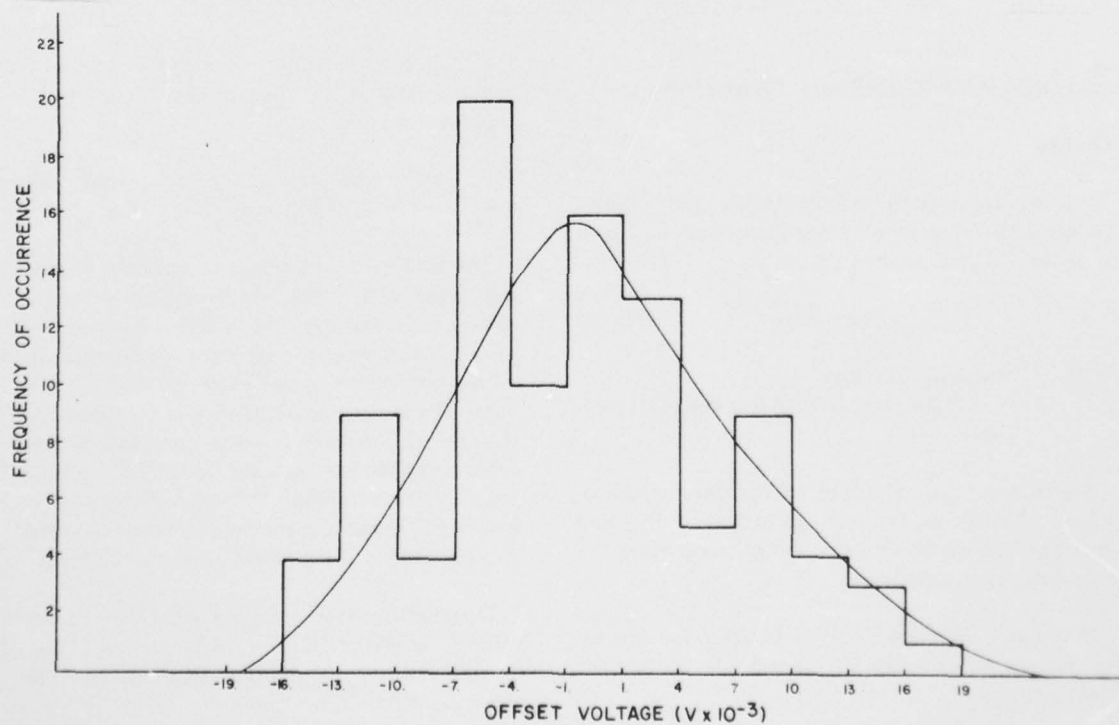


Figure E2. Histogram of Mark Products System III data (-10°F or -23.3°C).

$$a = \bar{y} - \beta \bar{x} \quad (\text{Eq E2})$$

$$\beta = \frac{\sum_{i=1}^n x_i y_i - n \bar{x} \bar{y}}{\sum_{i=1}^n x_i^2 - n \bar{x}^2} \quad (\text{Eq E3})$$

where n = number of readings to be reduced
 β = slope of the linear equation
 a = the y intercept.

The total error of the data (Δ) can be found by the equation

$$\Delta = \sum_{i=1}^n (y_i - a - \beta x_i)^2 \quad (\text{Eq E4})$$

An estimate of the variance(s) is given by¹⁵

$$s^2_{x/y} = \Delta / n - 2 \quad (\text{Eq E5})$$

The standard deviation (σ) is the square root of the variance and the coefficient of variation (δ) is defined as¹⁶

$$\delta = \sigma / \mu \quad (\text{Eq E6})$$

where μ = the mean of the data used to compute the standard deviation.

Computer Program

An extended Fortran program titled REGAN (REGression Analysis) was developed to compute the coefficient of variation for each calibration run. The program also determines the hysteresis area of the data and the average calibration value at each angle or load setting per data run.

3 SEQ RADIUS INDICATOR REGRESSION ANALYSIS

Theory

The SEQ calibration data were taken after the input data had been manipulated to produce a radius readout. The data cannot be reduced by a linear regression analysis since they do not follow the linear function response of the input parameters.

¹⁵Ang and Tang, p 254.

¹⁶Ang and Tang, p 126.

Therefore, the regression analysis was derived as described below.

The equation for which the system was programmed is

$$R_i = 10 \text{ ft} + 110 \text{ ft} \cos \Theta_i \quad (\text{Eq E7})$$

where R_i = the radius from center of rotation of crane to the load in feet
 Θ_i = the angle in degrees of the boom above the horizontal.

The radius meter itself has a linear response readout from its input voltage (V_i). The equation is

$$R_i = 120 \text{ ft} - 500 \Lambda_i \quad (\text{Eq E8})$$

The relationship between the angle of the boom and the meter input data is the combination of Eq E7 and E8 which is

$$\Lambda_i = .22 (1 - \cos \Theta_i) \quad (\text{Eq E9})$$

Eq E9 is the ideal response of the system; however, drift occurs within an electronic circuit. To compensate for drift, variable gain and zero control were placed in the meter circuit. With these factors, the relationship between the calibrated and uncalibrated (V_i) data becomes

$$\Lambda_i = a + \beta V_i \quad (\text{Eq E10})$$

Substituting Λ_i from Eq E10 into E9 gives the relationship between the boom angle and the uncalibrated voltage which is

$$V_i = .22 (1 - \cos \Theta_i) / \beta - a / \beta \quad (\text{Eq E11})$$

In a regression analysis, the a and β values are computed mathematically to match the uncalibrated data obtained from various angles Θ_i .

The total error (Δ) for a (n) number of the voltage reading V_i is:

$$\begin{aligned} \Delta &= \sum_{i=1}^n (V_i \text{ readings} - V \text{ calculated})^2 \\ &= \sum_{i=1}^n (V_i - (.22 (1 - \cos \Theta_i) - a) / \beta)^2 \quad (\text{Eq E12}) \end{aligned}$$

where V_i is the voltage reading corresponding to Θ_i .

If Δ is to have a minimum value, then

$$\partial \Delta / \partial a = 0 \quad (\text{Eq E13})$$

$$\partial \Delta / \partial \beta = 0 \quad (\text{Eq E14})$$

where ∂ is the partial differentiation operator.
Taking the partial derivative of Eq E12 gives

$$\begin{aligned} \partial \Delta / \partial a &= \sum_i^n (y_i - .22/\beta + .22 \cos \Theta_i / \beta + a/\beta)(1/\beta) \\ &= 0 \end{aligned} \quad (\text{Eq E15})$$

$$\begin{aligned} \partial \Delta / \partial \beta &= \sum_i^n 2 (y_i - .22/\beta + .22 \cos \Theta_i / \beta + a/\beta) \\ &\quad (.22/\beta^2 - .22 \cos \Theta_i / \beta^2 - a/\beta^2) \quad (\text{Eq E16}) \end{aligned}$$

Since $1/\beta \neq 0$, then $1/\beta^2 \neq 0$. These values can be factored out of Eq E15 and E16. Solving Eq E15 for β gives

$$\beta = .22n / \sum y_i - .22 \sum \cos \Theta_i / \sum y_i - a \times n / \sum y_i \quad (\text{Eq E17})$$

Eq E16 expands to

$$\begin{aligned} 0 &= .22 \beta \sum y_i - .22 \beta \sum y_i \times \cos \Theta_i - \beta a \sum y_i + .0968 \sum \cos \Theta_i \\ &\quad + .44 a n - .44 a \sum \cos \Theta_i - a^2 n - .0484 \sum \cos^2 \Theta_i \\ &\quad - .0484 n \end{aligned} \quad (\text{Eq E18})$$

Substituting β from Eq E16 into Eq E17 and collecting like terms gives

$$\begin{aligned} 0 &= .0484 \sum \cos \Theta_i - .22 \sum \cos \Theta_i \times a - .0484 \sum \cos \Theta_i \\ &\quad - .0484 n \sum \cos \Theta_i \times y_i / \sum y_i + .0484 \sum \cos \Theta_i \\ &\quad \times \sum \cos \Theta_i \times y_i / \sum y_i + .22 n a \times \sum \cos \Theta_i \times y_i / \sum y_i \end{aligned} \quad (\text{Eq E19})$$

Solving Eq E19 for a gives

$$\begin{aligned} a &= \{ .22 [\sum \cos \Theta_i - \sum \cos^2 \Theta_i - n \sum \cos \Theta_i \times y_i / \sum y_i \\ &\quad + \sum \cos \Theta_i \times \sum \cos \Theta_i \times y_i / \sum y_i] \} / \\ &\quad [\sum \cos \Theta_i - n \sum \cos \Theta_i \times y_i / \sum y_i] \quad (\text{Eq E20}) \end{aligned}$$

The total error (Δ) of the data can be found using Equation E12. Estimates of the variance and coefficient of variation are determined using Eq E5 and E6.

Computer Program

Computer program REGRAN was modified using Eq E20 and E17 to determine a and β and Eq E12 to determine the variance.

APPENDIX F:

FIELD TEST PROCEDURE

PART I - INTRODUCTION

1. Purpose. The purpose of this specification and procedure is to provide a detailed and uniform method for field testing of Load Indicating Device Systems (LIDS) for mobile construction and maintenance cranes. This testing is being performed so that the various types of LIDS on the market may be evaluated and compared in order to determine their accuracy and durability under various operating and environmental conditions.

2. Scope.

2.1 Testing is limited to cranes owned and operated by various districts of the U.S. Army Corps of Engineers. The use of these cranes can be classified in the following categories:

2.1.1 Mobile cranes on land used for construction purposes.

2.1.2 Mobile cranes on land used for maintenance purposes.

2.1.3 Cranes mounted on barges used for construction purposes.

2.1.4 Cranes mounted on barges used for maintenance purposes.

2.2 The operation of cranes differs from one category to the next, indicating that the use of the LIDS may be different for each category. This difference affords an opportunity to test the effectiveness of the LIDS under various conditions of use and environment.

PART II - SPECIFICATION

1. Visual Inspection.

1.1 General.

1.1.1 The LIDS shall first be inspected to determine the type: i.e., load moment computer, load indicator, boom angle or radius indicator, or load-angle or radius indicator.

1.1.2 The method of operation shall be determined: electronic, hydraulic, mechanical, or any combination thereof.

1.1.3 The presence or absence of a button or switch for the purpose of testing the system for proper functioning of all components shall be determined, including batteries if the system is so equipped.

1.1.4 The presence or absence of alarms for indication of overload and/or high and low boom angle conditions and the means for setting the limits to activate these alarms shall be determined.

1.1.5 Inspect maintenance records for frequency of repairs, recalibration, etc.

1.2 Display Module. The display module shall be inspected for the following conditions:

1.2.1 Location within the cab or within the sight of the operator.

1.2.2 Method of mounting to crane structure.

1.2.3 Apparent sturdiness of display module and its enclosure.

1.2.4 Simplicity of arrangement of display and controls, and method of setting controls.

1.2.5 Clarity of reading the display.

1.2.6 Alarm lights and buzzer.

1.2.7 Illumination for night operation.

1.3 Electronics Module. The electronics module if used shall be inspected for the following conditions:

1.3.1 Location within the crane cab or structure.

1.3.2 Method of mounting to crane structure.

1.3.3 Apparent sturdiness of electronics module and its enclosure.

1.3.4 Arrangement, clarity, and ease of operation of controls and switches.

1.4 Load Cell. The load cell shall be inspected for the following conditions:

1.4.1 Location on the crane or boom structure.

1.4.2 Method of applying load.

1.4.3 Method of transmitting load signal.

1.4.4 Method of preventing torsion for cell at dead end of even parts-of-line.

1.4.5 Number of sheaves in multi-sheave tensiometer.

1.4.6 Lubrication of all sheaves and pivots in multi-sheave tensiometer or load cell linkage.

1.5 Boom Angle or Radius Sensor. The boom angle or radius sensor shall be inspected for the following conditions.

1.5.1 Location on the boom.

1.5.2 Method of mounting to boom.

1.5.3 Apparent sturdiness of enclosure.

1.5.4 Means of locking sensor for shipment.

1.5.5 Method of transmitting boom angle signal.

1.5.6 Freedom of movement where applicable.

1.6 Connecting Cables or Hoses. The cables or hoses shall be inspected for the following conditions:

1.6.1 Sturdiness of construction of cable or hose.

1.6.2 Method of support from crane or boom structure.

1.6.3 Protection from damage.

1.6.4 Elimination of points of strain.

1.6.5 Sturdiness of construction of connectors and couplings.

1.6.6 Ability to resist water penetration.

1.7 Crane Sheaves. The sheaves in the crane boom and hook block shall be inspected to determine the adequacy of lubrication and freeness of rotation.

2. Test Conditions.

2.1 Testing shall be performed during as many weather conditions as practicable at all seasons of the year and in as many climatic environments as possible.

2.2 Cranes shall be operated in their normal manner wherever possible. Where this cannot be done, testing shall attempt to simulate actual conditions.

2.3 Loads shall be lifted directly vertically at all times.

2.4 Cranes on land shall be on a firm, level foundation, preferably on concrete. If the crane is equipped with outriggers, they shall be used and the crane bed shall be brought to level within 1°.

2.5 Total load to be lifted shall be weighed prior to tests, including hook block, overhaul ball, slings, chains, skids, buckets, and any other items which may be part of the load. Accuracy of weighing shall be to the nearest ¼ of 1%.

2.6 Gravity-type-pendulum visual boom angle indicators shall be thoroughly cleaned and properly lubricated prior to test.

2.7 The crane shall be operated by its regular operator or his alternate.

3. Test Limits.

3.1 The crane shall be operated at all times within safe limits as established by the manufacturer.

3.2 Outriggers shall be set properly on cranes equipped with them.

3.3 Tests shall be performed in a clear area large enough so that nothing but the crane is damaged in case of an accident.

PART III - PROCEDURE

1. Load Moment Computers.

1.1 General Preparation.

1.1.1 Prepare 4 weights corresponding to maximum loads for boom angles of 80° or maximum if less, 60°, 40° and 20° for the crane equipped with the LIDS to be tested. Verify the weights within ¼ of 1%. Weight shall include hook and block.

1.1.2 Reeve the hook block for the number of parts of line corresponding to the heaviest load. Set this on the computer module, if required.

1.1.3 Have a copy of operating instructions available and read it thoroughly before commencing to test.

1.1.4 Have available all data used by LIDS manufacturer in determining 100% moment curve of crane: dimensional data, weight and gravity center location of boom and counterweight, etc., so that moment display can be verified.

1.1.5 Determine the maximum angle to which the boom angle can be raised. If over 85°, set boom stops for 85° boom angle.

1.1.6 Turn the system on and allow to warm up for recommended length of time. Record the warm-up time.

1.1.7 Press test button. Observe and record results. Do not proceed unless test reactions agree with manufacturer's instructions in operator's manual.

1.2 Boom Angle Settings.

1.2.1 Conduct these tests with no load on the hook.

1.2.2 Set the low angle setting to zero, and raise the boom from the horizontal until the low angle alarm is deactivated. Record the angle.

1.2.3 Reduce the high angle setting until the high angle alarm is activated. Record both the indicated and actual angles.

1.2.4 Raise the boom to its maximum angle and then lower it again. The alarms should remain activated continuously during this test. Record the angle at which the alarms are deactivated.

1.2.5 Increase the upper boom angle settings

in steps of 10°, and repeat the above procedures at each step.

1.2.6 Raise the boom to the boom stops, and increase the high angle setting until the alarms are deactivated. Record the angle. Raise the low angle setting until the alarms are activated. Record the angle.

1.2.7 Repeat the high angle alarm tests in reverse, lowering the low angle setting in 10° steps.

1.2.8 At each step of increasing or decreasing boom angle, measure the radius to the load so that the indicated angle can be compared with its calculated value.

1.3 Load Moment Determination.

1.3.1 Select the load corresponding to 20° boom angle. Raise the boom to the stops and hook onto the load.

1.3.2 Raise the load about 1 foot off the ground. Lower the boom, raising the load as needed, until the first warning (85 or 90%) is activated. Record the angle. Continue lowering until the 100% warning is activated. Record the angle. At all times keep the load approximately 1 foot off the ground. Measure the radius at the points where the alarms are activated. Move sufficiently slowly so that instantaneous stops may be made at the alarm activation points.

1.3.3 Raise the boom sufficiently to deactivate the 100% alarm, and hold it at that point. Raise the load to the limit, and observe and record the effect of the moving load on the alarm and the meter indication.

1.3.4 Lower the boom sufficiently to activate the 100% alarm, and hold it at that point. Drop the load to the ground, and observe and record the effect of the moving load on the alarm and the meter indication.

1.3.5 In sequence, select the loads corresponding to 40°, 60°, and 80° or maximum boom angles and repeat the above procedures.

1.3.6 In each test, carefully observe and record the adequacy of load and boom angle display, the ease or difficulty in reading the display, and the steadiness of the display as the load "bounces."

2. Load Indicators.

2.1 General Preparation.

2.1.1 Prepare 4 weights corresponding to maximum loads for boom angles of 80° or maximum if less, 60°, 40° and 20° for the crane equipped with the LIDS to be tested. Verify the weights within ¼ of 1%. Weight shall include hook and block.

2.1.2 Reeve the hook block for the number of parts of line corresponding to the heaviest load. Set this on the appropriate module if so equipped.

2.1.3 Have a copy of operating instructions available and read it thoroughly before commencing to test.

2.1.4 Determine the maximum angle to which the boom can be raised. If over 85°, set boom stops for 85° boom angle.

2.1.5 Turn the system on (if electronic) and allow to warm up for recommended length of time.

2.1.6 Press test button (if system is so equipped). Observe and record results. Do not proceed unless test reactions agree with manufacturer's instructions in operator's manual.

2.2 Load Indication and Alarm.

2.2.1 Select the load corresponding to 20° boom angle. Set the load limit 30% heavier than the

load. With the boom at 20°, hook to the load. Slowly raise the load about one foot, and hold at that elevation.

2.2.2 Observe the load indication as given by the display module.

2.2.3 Reduce the load limit setting until the first alarm is activated (usually the amber light). Record the value of the setting. Continue reducing the setting until the second alarm is activated (usually the red light and horn). Record the value of the setting. This value should correspond to the load.

2.2.4 Reset the load limit setting to 30% heavier than the load. Raise the load as high as possible and hold. Record the weight as indicated by the display while raising and while holding. Lower the load close to the ground and hold. Record the weight as indicated by the display while lowering and while holding.

2.2.5 In sequence, select the loads corresponding to 40°, 60°, and 80° or maximum boom angles and repeat the above procedures.

2.2.6 In each test, carefully observe and record the adequacy of load and boom angle display, the ease or difficulty in reading the display, and the steadiness of the display as the load "bounces."

3. Boom Angle Indicators. Follow the procedure as given in Section 1.2, Boom Angle Settings, under Load Moment Computers.

APPENDIX G:

CANDIDATE SPECIFICATION FOR CRANE OVERLOAD WARNING DEVICES (LOAD MOMENT COMPUTERS)

1. Scope: This specification applies to Load Moment Computers for mounting on mobile construction cranes.

2. Applicable Publications: The following publications of the issues listed below, but referred to thereafter by basic designation only form a part of this specification to the extent indicated by the reference thereto.

2.1. Society of Automotive Engineers (SAE)

SAE J159 SAE Recommended Practice for Load Moment Warning System, March 1974.

SAE J376a SAE Recommended Practice for Load Indicating Systems in Lifting Crane Service, October 1974.

SAE J375a SAE Recommended Practice for Radius-of-Load and Boom Angle Measuring System, August 1972.

2.2. U.S. Occupational Safety and Health Administration, Federal Register No. 203 Vol. 37 Cranes and Derricks other than Vessels' Gear, October 1972.

2.3. U.S. Department of Defense

MIL-S-901C Requirements for Shock Test (High Impact)

MIL-M-16034A Meters, Electrical Indicating

3. General Requirements:

3.1. The contractor shall manufacture, install, and test for acceptance Load Moment Computers (LMC) in the quantity specified, to the site(s) and crane(s) as indicated elsewhere in this document.

3.2. LMCs shall comply with the society of Automotive Engineers (SAE) recommendations J375 and J376, except as noted below. All components will be tested in accordance with military specification MIL-S-901C and comply with military standard MIL-M-16034A. Furthermore, the devices will comply with all requirements of the U.S. Bureau of

Labor Standards, Safety and health regulations for both long-shoring and construction.

3.3. The contractor shall obtain from the crane manufacturer(s) a certified copy of the crane load-radius chart(s), the tipping load in the least stable position, and the maximum lifting capabilities of the crane(s) if limited by some factor other than tipping. A copy of these ratings for each standard boom length shall be provided to the Contracting Officer prior to acceptance of the Load Moment Computer.

3.4. All attachment of sensing devices to the boom or other load-carrying part of the crane shall be by clamping or bolting. Holes may be drilled only in special plates provided in place by the crane manufacturer for that purpose. Welding will not be permitted.

3.5. The contractor shall have documentation that the attachment of the LMC will not void the warranty of the crane(s). The system is to be installed in a method approved by the manufacturer of the crane.

4. System Compatibility:

4.1. LMCs shall operate electronically. They will utilize the crane power supply and have fuses which prevent overloading damage to the system.

4.2. Any operating variable, such as, parts-of-line, outriggers, jib length, or multiple hooks, specified for the warning system shall have a positive means of selection. It shall not require a replacement or removal of parts to make a change in the variable.

4.3. The load cell or tensiometer shall be attached in such a location that the cable will be protected if extended along or within the boom. When any part of a LMC is used as part of the structural or support system of a crane, that part's strength margin shall be at least 25 percent higher than the strength margin of those members supporting it. The LMC is not to be part of any failure mode of a crane, mechanical or electrical. The load cell and its housing shall be constructed so that it cannot be twisted by stretch or spin of the wire rope. The load cell shall also safely withstand an overload of three times the maximum force without damage to its load-sensing capabilities. If a multiple-sheave tensiometer is used, it shall be attached to the crane or boom by some means such that it can float on the

load line. The tensiometer shall not reduce the life of the wire rope by more than 20 percent.

5. System Operation and Components:

5.1. The LMC shall be fully operational over an environment of -20°F to $+120^{\circ}\text{F}$ (-29°C to $+49^{\circ}\text{C}$) and a relative humidity of 5 percent to 100 percent. If zeroing the instruments is required for temperature or aging it shall be accomplished without removing parts or using tools and shall have a positive locking system.

5.2. Accuracy of LMC will meet the specifications of section 4.3 of the SAE Recommended Practice J159, "Load Moment Warning Systems," the rated load being based on a safety factor of 75 percent or lower percentage of the tipping or other failure mode maximum load.

5.3. An effective and simple procedure for checking circuits and alarms for proper functioning shall be furnished as a built-in part of the system. This check shall also indicate whether or not the system is fully operative. Adjustments shall not be required after initial setting of the LMC.

5.4. All components shall be enclosed in weatherproof, corrosion-resistant housings. Load cells shall withstand shock loads to 2 g along the measuring axis and 5 g along any other axis, without damage or change in calibration. Boom angle sensor shall withstand shock loads of 2 g along the lateral axis and 5 g along the vertical or longitudinal axis without damage or change in calibration, when the system is in operation with the pendulum unlocked. A positive means of locking the angle sensor for shipment shall be provided. When the pendulum is locked the sensor shall withstand a shock load of 15 g along any axis. Sensor housings shall not be damaged by these loads.

5.5. When the 100 percent level of the crane's rated capacity is reached, a red warning light and a steady alarm with 82 ± 3 db level at 5 ft (1.5 m), shall trigger. At the 85 percent level of rated load a yellow flashing indicator shall actuate.

5.6. A system's readout shall comply with the standards outlined in section 4.4 of the SAE Recommended Practice J159, "Load Moment Warning System."

5.7. All signal transmission lines shall be in-

stalled so that maximum protection from any damage is afforded, whether due to crane operation or extraneous causes.

5.8. Readout dials shall be illuminated for night operation.

6. Tools: Any special tools or equipment required for installation, operation and/or maintenance shall be furnished with the LMC.

7. Manuals: Before installation and acceptance of the LMC, five copies of the following shall be provided to the Contracting Officer:

7.1. Complete installation instructions.

7.2. Complete operating instructions.

7.3. Complete maintenance instructions, including schematic drawings of all electronic circuits.

7.4. Complete parts list, including drawings showing the location of each part.

8. Maintenance: Replacement of any major component shall not require major recalibration of the LMC. Recalibration in the field by untrained personnel shall be possible.

9. Warranty: The LMC shall be warranted by the manufacturer for a period of one year against all defects of material and workmanship. Defects not repaired by the manufacturer within one month of notification will be repaired by the Government, and costs thereof will be charged to the manufacturer.

10. Test Procedure:

10.1. General test requirements will meet the recommended standard in section 6.1 of the SAE Recommended Practice J159.

10.2. Testing in the field for equipment performance shall be conducted in the following manner.

a. A load shall be applied to the crane by means of a (fixed anchor) equipped with a calibrated load indicating device with an accuracy of ± 1 percent. If additional weights are used, such as sensors, blocks, etc., which are not included in the crane load rating chart, they shall be known to an accuracy of ± 1 percent.

b. Perform test for activating the 85 percent alarm and the 100 percent alarm for three crane

radii, at a desired radius in the minimum 10 percent range, the middle 10 percent and upper 10 percent ranges. Measure the boom radius by use of a steel tape. (Example, a crane with 110 ft [33.5 m] boom only has a range from 20 to 105 feet [6.1 to 32.0 m], therefore, the lower 10 percent range is 20 to 28.5 feet [6.1 to 8.7 m] ; middle, 58.25 to 66.75 feet [17.8 to 20.3 m]; upper, 96.5 to 105 feet [29.4 to 32.0 m]. A test is made at 25, 60, and 100 ft [7.6, 18.2, and 30.5 m].)

c. Record the loads at which the alarm activates. Refer to other related sections in this document if the LMC has load, radius, or angle indicators.

10.3. Computations for the system actuation points shall be determined as follows:

$$[(\text{Rated Load} - \text{Test Load}) / \text{Rated Load}] \times 100\%$$

= % Error.

APPENDIX H:

CANDIDATE SPECIFICATION FOR CRANE LOAD INDICATING SYSTEMS

1. Scope: This specification applies to Load Indicating Devices for mounting on mobile construction cranes.

2. Applicable Publications: The following publications of the issues listed below, but referred to thereafter by basic designation only form a part of this specification to the extent indicated by the reference thereto.

2.1. Society of Automotive Engineers (SAE)
SAE J376a SAE Recommended Practice for
Load Indicating Systems in Lift-
ing Crane Service, October
1974.

2.2. U.S. Occupational Safety and Health Ad-
ministration. Federal Register No. 203 Vol 37
Cranes and Derricks Other Than Vessels' Gear,
October 1972.

2.3. U.S. Department of Defense
MIL-S-901C Requirements for Shock
Test (High Impact)
MIL-M-16034A Meters, Electrical Indicating.

3. General Requirements:

3.1. The contractor shall manufacture, install, and test for acceptance Load Indicating Devices (LIDS) in the quantity specified, to the site(s) and crane(s) as indicated elsewhere in this document.

3.2. LIDS shall comply with all requirements of the U.S. Bureau of Labor Standards, Safety and Health Regulations for both long-shoring and construction. All component testing shall be conducted in accordance with military specification MIL-S-901C. Components will comply with military standard MIL-M-16034A. Furthermore, LIDS shall comply with the Society of Automotive Engineers (SAE) Recommendation SAE J376a, except as noted below.

4. System Compatibility:

4.1. All attachments of sensing devices to the boom or other load-carrying part of the crane shall

be by clamping or bolting. Holes may be drilled only in special plates provided in place by the crane manufacturer for that purpose. Welding will not be permitted.

4.2. The contractor shall have documentation which verifies that the attachment method the system utilizes is approved by the crane manufacturer and does not void the warranty of the crane.

4.3. The LIDS system shall operate hydraulically or electronically. Electronic systems shall utilize the crane's power supply and have fuses which prevent overloading damage to the system.

4.4. An operating variable, such as parts-of-line, outriggers, jib length, or multiple hooks, specified for the warning system shall have a positive means of selection. It shall not require a replacement or removal of parts to make a change in the variable.

4.5. The load cell or tensiometer shall be attached in such a location that the cable will be protected if extended along or within the boom. When any part of a LID is used as part of the structural or support system of a crane, that part's strength margin shall be at least 25 percent higher than the strength margin of those members supporting it. The LID is not to be part of any failure mode of a crane, mechanical or electrical. The load cell and its housing shall be constructed so that it cannot be twisted by stretch or spin of the wire rope. The load cell shall also safely withstand an overload of three times the maximum force without damage to its load-sensing capabilities. If a multiple-sheave tensiometer is used, it shall be attached to the crane or boom by some means such that it can float on the load line. The tensiometer shall not reduce the life of the wire rope by more than 20 percent.

5. System Operation and Components:

5.1. The LIDS shall be fully operational over an environment of -20°F to 120°F (-29°C to $+49^{\circ}\text{C}$) and a relative humidity of 5 percent to 100 percent. If zeroing the instruments is required for aging effects, it shall be accomplished without removing parts or using tools and shall have a positive locking system.

5.2. Accuracy of a load indicating system shall not have an error of more than 3 percent indicated load under the actual load to 5 percent indicated load over the actual load. These percentages apply at

least to the minimum and maximum rated lift capacity of a crane over its boom angle range. A visual indicator shall be provided when the indicator does not meet this specification for values below the minimum lift capacity of the crane.

5.3. An effective and simple procedure for checking circuits and alarms for proper functioning shall be furnished as a built-in part of the system. This check shall also indicate whether or not the system is fully operative. Adjustments shall not be required after initial setting of the LIDS.

5.4. All components shall be enclosed in weather proof, corrosion-resistant housings. Load cells shall withstand shock loads to 2 g along the measuring axis and 5 g along any other axis, without damage or change in calibration. Sensor housings shall not be damaged by these loads.

5.5. When set points are employed in a system, they shall be equipped with an audible signal which has an 82 ± 3 db level at a 5 ft (1.5 m) distance and a red warning light, clearly visible to the operator. The operator shall be able to pre-set the load to an accuracy of at least 10 percent of the minimum lift capacity of the crane or 1000-lb (453.6 kg) increments, whichever is smaller.

5.6. Load values shall be readable for night operation. The device readout shall be located within a range where an operator can obtain readings without interrupting his normal mode of operation and without causing an occupational hazard.

5.7. All transmission lines shall be installed so that maximum protection from any damage is afforded, whether due to crane operation or extraneous causes.

5.8. Minimum resolution shall permit a clear reading of the load values within the accuracy of the system.

6. Tools: Any special tools or equipment required for installation, operation and/or maintenance shall

be furnished with the LIDS. Hydraulic systems shall include a quart can of hydraulic fluid and a pump for use in re-charging the system.

7. Manuals: Before installation and acceptance of the LIDS, five copies of the following shall be provided to the Contracting Officer:

7.1. Complete installation instructions.

7.2. Complete operating instructions.

7.3. Complete maintenance instructions, including schematic drawings of all electronic circuits.

7.4. Complete parts list, including drawings showing the location of each part.

8. Maintenance: Replacement of any major component shall not require major recalibration of the LIDS. Recalibration in the field by untrained personnel shall be possible.

9. Warranty: LIDS shall be warranted by the manufacturer for a period of one year against all defects of material and workmanship. Defects not repaired by the manufacturer within one month of notification will be repaired by the Government, and costs thereof will be charged to the manufacturer.

10. Performance Evaluation Test:

10.1. LIDS shall be tested in accordance with the general requirements outlined in section 6 of SAE Recommended Practice J376a with the exception of sentence 6.2.1(b). The accuracy of the system is defined as 97 to 105 percent.

10.2. For multi-sheave hooks, readings of the indicated load shall be taken for when the cables are raised and halted and lowered and halted (for known weights) or raised to a set load and lowered to a set load (for a fixed anchor). This accounts for pulley friction, therefore, the average readout should be used.

APPENDIX I:

CANDIDATE SPECIFICATION FOR RADIUS OF LOAD AND BOOM ANGLE MEASURING SYSTEMS

1. Scope: This specification applies to Radius of Load or Boom Angle Indicating Systems for mounting on mobile construction cranes.

2. Applicable Publications: The following publications of the issues listed below, but referred to thereafter by basic designation only form a part of this specification to the extent indicated by the reference thereto.

2.1. Society of Automotive Engineers (SAE)
SAE J375a SAE Recommended Practice for Radius-of-Load and Boom Angle Measuring System, August 1972.

2.2. U.S. Occupational Safety and Health Administration. Federal Register No. 203 Vol 37 Cranes and Derricks Other Than Vessels' Gear, October 1972.

2.3. U.S. Department of Defense
MIL-S-901C Requirements for Shock Test (High Impact)
MIL-M-16034A Meters, Electrical Indicating.

3. General Requirements:

3.1. The contractor shall manufacture, install, and test for acceptance Angle Indicating Devices (AIDS) and Radius of Load Devices (RLDS) in the quantity specified, to the site(s) and crane(s) as indicated elsewhere in this document.

3.2. AIDS and RLDS shall comply with all requirements of the U.S. Bureau of Labor Standards, Safety and Health Regulations for both long-shoring and construction. All component testing shall be conducted in accordance with military specification MIL-S-901C. Components will comply with military standard MIL-M-16034A. Furthermore, AIDS and RLDS shall comply with the Society of Automotive Engineers (SAE) Recommendation ASE J375a, except as noted below.

4. System Compatibility:

4.1. All attachment of sensing devices to the boom or other load-carrying part of the crane shall be by clamping or bolting. Holes may be drilled only in special plates provided in place by the crane manufacturer for that purpose. Welding will not be permitted.

4.2. The contractor shall have documentation which verifies that the attachment method the system utilizes is approved by the crane manufacturer and does not void the warranty of the crane.

4.3. The AIDS and RLDS system shall operate electronically or hydraulically. Electronic systems shall utilize the crane's power supply and have fuses which prevent overloading damage to the system.

4.4. Any operating variable, such as, parts-of-line, outriggers, jib length, or multiple hooks, specified for the warning system shall have a positive means of selection. It shall not require a replacement or removal of parts to make a change in the variable.

5. System Operation and Components:

5.1. The AIDS and RLDS shall be fully operational over an environment of -20°F to 120°F (-29°C to $+49^{\circ}\text{C}$) and a relative humidity of 5 percent to 100 percent. If zeroing the instruments is required for aging effects, it shall be accomplished without removing parts or using tools and shall have a positive locking system.

5.2. Accuracy of a radius of load device shall indicate the radius within the limit of the values determined by taking ± 2.0 percent of the maximum boom radius and applying the band across the scale. Accuracy of AIDS shall comply with the standard for angle indicators in the paragraphs 3.1 of SAE J375a.

5.3. An effective and simple procedure for checking circuits and alarms for proper functioning shall be furnished as a built-in part of the system. This check shall also indicate whether or not the system is fully operative. Adjustments shall not be required after initial setting of the system.

5.4. All components shall be enclosed in weather proof, corrosion-resistant housings. A positive means of locking the angle sensor for shipment shall be provided. Boom angle sensor shall withstand shock loads of 2 g along the lateral axis and 5 g along the vertical or longitudinal axis without damage or

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EVALUATION OF LOAD-INDICATING DEVICES (LIDS) FOR MOBILE CONSTRU--ETC(U)
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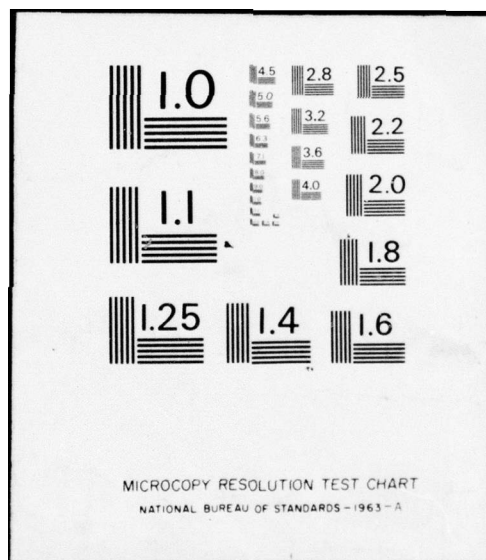
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change in calibration, when the system is in operation with the pendulum unlocked. When the pendulum is locked, the sensor shall withstand a shock load of 15 g along any axis. Sensor housings shall not be damaged by these loads.

5.5. When set points are employed in the system, they shall be equipped with an audible signal which has 82 ± 3 db level at a 5 ft (1.5 m) distance and a red warning light, clearly visible to the operator. The operator shall be able to pre-set the angle to an accuracy of at least $\frac{1}{2}$ degree for angle indicators and 1 percent of the maximum radius-of-load indicators. Indicators shall be illuminated for night operation.

5.6. Minimum resolution shall permit clear reading of the indicated values within the accuracy of the system.

6. Tools: Any special tools or equipment required for installation, operation and/or maintenance shall be furnished with the AIDS and RLDS. Hydraulic systems shall include a quart can of hydraulic fluid and a pump for use in re-charging the system.

7. Manuals: Before installation and acceptance of the AIDS and RLDS, five copies of the following shall be provided to the Contracting Officer:

7.1. Complete installation instructions.

7.2. Complete operating instructions.

7.3. Complete maintenance instructions, including schematic drawings of all electronic circuits.

7.4. Complete parts list, including drawings showing the location of each part.

8. Maintenance: Replacement of any major component shall not require major recalibration of the AIDS and RLDS. Recalibration in the field by untrained personnel shall be possible.

9. Warranty: AIDS and RLDS shall be warranted by the manufacturer for a period of one year against all defects of material and workmanship. Defects not repaired by the manufacturer within one month of notification will be repaired by the Government, and costs thereof will be charged to the manufacturer.

10. Performance Evaluation Test:

10.1. The required performance evaluation test is outlined in section 5 of the appendix to SAE Recommended Practice J375a.

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